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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

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A PHOTO-ELECTRIC STUDY OF ALGOL

By JOEL STEBBINS

ABSTRACT

Variable star, Algol; photometric study.—Observations during 1919–1920 with a photo-electric photometer give a new *light-curve* for this star which is considerably more accurate than the curve obtained in 1909–1910 with the selenium photometer (Fig. 1, Table XII). Besides confirming the secondary minimum and the continuous variation between minima, the new results show an effect due to the ellipsoidal shape of the components of the system. The phase of the secondary minimum indicates that there can be no rapid motion of the line of apsides of an elliptical orbit; in fact all of the photometric evidence points to a circular orbit. Corrections to the ephemeris for the times of minimum are given. Neglecting the light of the third body the *elements of the eclipsing binary system* are derived (Table XI), but it is pointed out that definitive values of the elements cannot be found until measures of the spectrum and magnitude of the third component and a very accurate parallax for Algol are available. The elements found agree closely with those obtained in 1909–1910. Certain differences suggest a *color-index for the satellite* which would make it somewhat yellower than the primary.

Constancy of three comparison stars.—The star *δ Persei* is suspected of variation to the extent of $0^{M}.04$ or $0^{M}.05$, but *l and π Persei* were found to be constant within $0^{M}.01$.

Photo-electric photometer for stars.—*The precision* which may be reached is indicated by the results in Tables VII and XIII.

Since the determination of the light-curve of Algol in 1909–1910 with the selenium photometer,[1] the only confirmation of the existence of the secondary minimum that has come to my attention is by M. Maggini, of Florence,[2] who worked in lights of two colors

[1] *Astrophysical Journal*, **32**, 185, 1910.

[2] *Popular Astronomy*, **26**, 380, 1918.

with a visual photometer. However, he did not find any variation of light between minima, and from his published data I am unable to determine how it was that the star was measured with no apparent change between eclipses.

Quite often in the past, variations in the photometric period of Algol have been attributed to the effect of an unseen third body, and with the spectroscopic detection of a companion to the system, with a period of 1.9 years, it is possible to take another step in the study of this star. If the relative orbit of the eclipsing satellite is elliptical and the line of apsides is in motion, we would have one explanation for the displacement of the times of primary minimum. In particular, the position of the secondary minimum with respect to the primary is a very delicate test of the correctness of the elliptical orbit, and it was to establish any change in the time of secondary minimum that after the lapse of ten years I decided to make a new determination of the light-curve.

Algol was the first star to be studied exhaustively with the selenium photometer when this instrument had been made sensitive enough to take accurate measures of second-magnitude stars, and fair measures of the third magnitude, or of Algol at greatest eclipse. In 1913 the experiments with selenium were definitely abandoned in favor of the photo-electric cells, which were being developed in our physics laboratory by Dr. Jakob Kunz. Since that time the photo-electric photometer has reached a stage of progress where, with the same 12-inch telescope, objects of photographic magnitude 6.0, or even fainter, can be measured more accurately than any stars whatever with the selenium photometer.

During the winter of 1919–1920 an entirely new series of measures of Algol has been taken with the new instrument, and the results are given in this paper. For convenience the earlier work with selenium will be designated as the series of 1910, and the new work the series of 1920.

In 1910 the comparison stars used were α Persei and δ Persei. As Algol has a spectrum of class B8 and α Persei of F5, this comparison star was not considered at all for the new work, it being our present practice to observe stars as nearly of the same spectral class as are available. δ Persei, spectrum B5, is an excellent com-

parison object, and many measures were taken of it. However, on several occasions δ was found to be unmistakably faint to the extent of $0^{M}.04$ or $0^{M}.05$, indicating that it is possibly an eclipsing variable of small range, though a spectroscopic orbit has not been determined. This variation of δ may have affected slightly the measures of Algol at primary minimum in 1910. but not enough to be noticed. When the trouble was detected this time, the whole series with δ was discarded for the study of Algol, but the measures will be used for the test of the light of δ. In fact, no better comparison star can be found than a thoroughly studied variable like Algol, if observed between eclipses, as its variations are known to a certain degree, whereas a so-called constant star taken at random may vary in any unknown fashion.

TABLE I

COMPARISON STARS

H.R.	Star	Harvard Magnitude	Photo-electric Magnitude	Spectrum
936	β Persei	2.1–3.2	(5.0)	B8
1122	δ Persei	3.10	3.02	B5
1002	l Persei	4.98	5.02	A2
879	π Persei	4.62	4.66	A2

By means of neutral shade-glasses to cut down the light of bright stars, it is practicable to use fainter objects for comparison stars, and in this case the two stars l Persei and π Persei make a very good combination when Algol is measured through a shade. The stars observed in 1920 are given in Table I. The rough photo-electric magnitude is derived from the Harvard visual magnitude, the "color-equation" of the installation according to revised measures being $0^{M}.70$. The same shade-glasses were used as in previous work,[1] and with shade III on Algol, which reduces the light 2.8 magnitudes, the variable at maximum is very nearly equal to l, and a quarter of a magnitude fainter than π. Near primary minimum, by changing to the lighter shade II the apparent light of Algol can still be kept about the same as the comparison stars. The positions of l and π in the sky, one on

[1] *Astrophysical Journal*, **49**, 346, 1919.

each side of Algol, give a most excellent elimination of the atmospheric extinction, as the visual differential correction between Algol and the mean of the two stars does not exceed $0^{\mathrm{M}}.002$ from sidereal time $21^{\mathrm{h}}.0$ to $7^{\mathrm{h}}.0$.

There are many measures during the series of 1920 which give the difference between l and π with only a small extinction correction, and dividing these we have for the difference, π brighter than l, the results shown in Table II.

TABLE II

DIFFERENCE BETWEEN l AND π PERSEI

November 1919	$0^{\mathrm{M}}.259$	±	$0^{\mathrm{M}}.0009$
December 1919—January 1920	0.259	±	0.0021
October 1920	0.256	±	0.0029
Adopt	$0^{\mathrm{M}}.259$	±	$0^{\mathrm{M}}.0012$

There is no indication that either l or π was variable in light.

Another constant to be determined was the difference in the absorptive powers of the two shades II and III, which for Algol have approximately the values $1^{\mathrm{M}}.66$ and $2^{\mathrm{M}}.82$. It is only the difference that enters into the result, and not the total absorption of either shade. The various determinations are as follows:

TABLE III

DIFFERENCE BETWEEN SHADES II AND III

Other stars, average for spectrum B8	$1^{\mathrm{M}}.146$	Neglecting dark current
Direct measures of Algol	1.147	
Direct measures of Algol	1.163	With correction for dark current
From fit of light-curve at primary minimum	1.169	
Adopt	$1^{\mathrm{M}}.160$	

The round figure of $1^{\mathrm{M}}.160$ was adopted more or less arbitrarily. When two stars of considerable difference in brightness are compared in rapid succession, the residual dark current from the brighter star, which lasts for one or two minutes, is added on to the light-effect from the fainter one. In regular work it is our custom to apply the same correction to both stars, because in bright moonlight the effect of the background of the sky is then

simply included as an addition to the correction for dark current. The difference between the two reductions with or without the dark current is generally of the order of a hundredth of a magnitude for one whole magnitude, or a difference in scale of say 1 per cent.

The photo-electric measures of Algol are given in Tables IV and V. The phase is computed from the final adopted epoch of minimum, and was reduced to the sun by Pannekoek's table. In Table IV, near primary minimum, each difference of magnitude is always referred to *l* Persei, + meaning Algol brighter than *l*, and is the mean of two sets of measures on the variable, taken ordinarily in the order: two readings on Algol, four on *l*, four on Algol, four on π, two on Algol, and so on. The only exception was on J.D. 2422281, when a number of sets were taken with *l* alone. In Table V each difference of magnitude is the mean of three sets, except where noted differently in the last column. Here the means for *l* and π have been taken separately, though the measures overlap, the observing schedule being as before. All measures in both tables have been corrected for atmospheric extinction, and the π sets have been corrected by $0^{M}259$ to reduce to *l*.

The present period of Algol was computed from Hellerich's elements.[1] On comparison with his elements III the photo-electric observations give, by a graphical solution for the primary minimum, a correction of $-0^{h}11=-0^{d}0046$. Using his predicted period and the present determination of the epoch we have

$$\text{Minimum}=\text{J.D. } 2422321.5947+2^{d}867301\cdot E,$$

from which the phases in Tables IV and V were computed.

In October 1920 Algol was observed during primary minimum on three nights as an additional check on the period and the light at minimum. The measures were taken exactly as those in Table IV, each observation being with the two comparison stars *l* and π, and shade II was used throughout. The results are in Table VI, where the computed phase in the fourth column is from Hellerich's elements III, uncorrected, while the observed phase in the next column is based upon the light-curve of the present series.

[1] *Astronomische Nachrichten*, **209**, 227, 1919.

TABLE IV

Observations of Algol at Primary Minimum

J.D. 242	G.M.T.	Phase	Difference of Magnitude	Shade, Comparison Star
2275 (Nov. 12, '19)	$12^{h}47^{m}.8$	$-4^{d}.31$	$-0^{M}.055$	III
	13 0.0	−4.11	− .116	III
	13 13.8	−3.87	− .112	III
	13 27.2	−3.65	− .186	III
	13 38.4	−3.47	− .165	III
	13 48.6	−3.29	− .180	III
	14 01.6	−3.07	− .292	III
	14 13.3	−2.89	− .333	III
	14 24.0	−2.70	− .356	III
	14 37.6	−2.47	− .427	III
	14 50.5	−2.26	− .478	III
	15 00.3	−2.10	− .571	III
	15 16.4	−1.83	− .628	II
	15 27.4	−1.65	− .732	II
	15 40.8	−1.42	− .808	II
	15 53.3	−1.22	− .881	II
	16 05.3	−1.02	− .958	II
	16 17.2	−0.82	−1.000	II
	16 41.2	−0.41	−1.130	II
	16 51.4	−0.25	−1.207	II
	17 01.4	−0.08	−1.173	II
	17 14.1	+0.13	−1.228	II
	17 25.1	+0.31	−1.171	II
	17 35.1	+0.48	−1.138	II
	17 53.2	+0.79	−1 067	II
	18 06.0	+1.00	− .974	II
	18 18.9	+1.21	− .932	II
	18 48.0	+1.69	− .706	II
	18 59.6	+1.89	− .632	II
	19 10.8	+2.08	− .569	II
	19 27.0	+2.35	− .456	III
	19 38.2	+2.53	− .410	III
	19 50.0	+2.73	− .362	III
	20 03.8	+2.96	− .282	III
	20 14.8	+3.15	− .218	III
	20 25.8	+3.33	− .219	III
	20 48.5	+3.71	− .116	III
	21 00.0	+3.90	− .096	III
	21 10.4	+4.07	− .071	III
2278	15 21.7	+1.44	− .768	II
	15 31.8	+1.61	− .719	II
	15 42.2	+1.78	− .666	II
	15 54.0	+1.98	− .588	II
	16 04.4	+2.15	− .530	II
	16 14.4	+2.31	− .460	II
	16 25.9	+2.50	− .410	II
	16 36.4	+2.69	− .352	II
	16 46.4	+2.85	− .305	II
	17 07.3	+3.19	− .238	III
	17 21.0	+3.43	− .161	III
	17 35.2	+3.67	− .145	III
	17 57.9	+4.04	− .087	III
	18 11.1	+4.26	− .043	III
	18 24.1	+4.48	− .022	III
	18 39.0	+4.73	− .017	III
	18 52.2	+4.95	+ .010	III
	19 05.1	+5.17	.000	III
	19 19.4	+5.39	.000	III
	19 31.4	+5.60	− .006	III
2278	$19^{h}42^{m}.8$	$+5^{d}.80$	$+ {}^{M}.001$	III
	20 12.6	+6.29	+ .003	III
	20 24.0	+6.47	+ .003	III
2281	13 07.8	+2.47	−0.440	III
	13 25.5	+2.69	− .379	III
	13 37.0	+2.88	− .316	III
	13 48.6	+3.07	− .254	III
	14 00.6	+3.27	− .218	III
	14 10.6	+3.44	− .174	III
	14 25.8	+3.69	− .122	III
	14 38.0	+3.89	− .088	III
	14 50.8	+4.11	− .066	III
	15 05.2	+4.35	− .028	III *l*
	15 17.9	+4.57	− .012	III *l*
	15 29.6	+4.76	+ .001	III *l*
	15 41.6	+4.96	+ .003	III *l*
	15 53.5	+5.16	+ .001	III *l*
	16 05.8	+5.37	− .006	III *l*
	16 19.2	+5.59	+ .006	III *l*
	16 31.2	+5.79	− .006	III *l*
	16 41.9	+5.97	+ .006	III *l*
	16 55.9	+6.20	+ .007	III
	17 08.4	+6.41	+ .002	III
	17 20.4	+6.61	− .006	III
2321	15 17.4	+1.11	− .902	II
	15 35.8	+1.43	− .810	II
	15 51.8	+1.69	− .692	II
	16 08.8	+1.97	− .590	II
	16 24.4	+2.23	− .498	II
	16 37.2	+2.45	− .425	II
	17 03.6	+2.89	− .315	III
2341	12 03.9	−3.86	− .150	III
	12 18.0	−3.63	− .135	III
	13 00.1	−2.93	− .310	III
	13 26.6	−2.49	− .432	II
	13 42.0	−2.23	− .526	II
	13 55.2	−2.01	− .582	II
	14 12.4	−1.71	− .674	II
	14 29.3	−1.43	− .807	II
	14 44.6	−1.18	− .874	II
	15 13.2	−0.71	−1.074	II
	15 29.2	−0.43	−1.124	II
2381	13 27.4	−5.97	+ .016	III
	13 42.9	−5.70	+ .032	III
	14 00.3	−5.41	− .008	III
	14 14.2	−5.18	− .014	III
	14 28.7	−4.94	− .013	III
	14 42.2	−4.71	+ .010	III
	14 58.2	−4.45	− .028	III
	15 13.2	−4.21	− .074	III
	15 27.1	−3.93	− .094	III
2384	13 05.2	−3.15	− .260	III
	13 18.4	−2.94	− .296	III
	13 32.4	−2.71	− .365	III
	13 47.6	−2.45	− .438	II
	13 58.4	−2.27	− .506	II
	14 10.1	−2.08	− .574	II
	14 27.8	−1.79	− .694	II
	14 39.5	−1.59	− .764	II
	14 51.5	−1.39	− .849	II

NOTES

J.D. 2422275—Measures at first were through smoke which gradually cleared. After about two hours the conditions were good.

2341—Sky only fair.

From the means in the last column of Table VI there is found for the correction to the ephemeris from Hellerich's elements III,

$$-0^{h}.30 \pm 0^{h}.007.$$

As the correction of the previous season was $-0^{h}.11$, we see that the ephemeris has run off $0^{h}.19 = 11$ minutes in the course of 298

TABLE V

OBSERVATIONS OF ALGOL AT SECONDARY MINIMUM AND BETWEEN MINIMA

J.D. 242	G.M.T.	Phase	Difference of Magnitude	Comparison Star, Sets	J.D. 242	G.M.T.	Phase	Difference of Magnitude	Comparison Star, Sets
2265	$15^{h}15^{m}$	$33^{h}.40$	$-0^{M}.016$	*l*, 2	2317	$13^{h}26^{m}$	$40^{h}.89$	$+0^{M}.040$	*l*
2268	14 04	35.41	− .009	*l*		13 36	41.06	+ .030	π
	14 30	35.84	− .006	*l*	2319	17 16	23.83	+ .035	*l*
	15 04	36.41	− .004	*l*		17 23	24.02	+ .036	π
	15 27	36.80	+ .013	*l*	2333	15 39	14.19	+ .017	*l*
	17 06	38.44	+ .062	*l*		15 47	14.33	+ .021	π
	17 27	38.80	+ .045	*l*	2335	13 27	59.99	+ .018	*l*
	18 37	39.96	+ .031	*l*		13 37	60.15	+ .014	π
	19 01	40.36	+ .021	*l*	2337	12 18	38.07	+ .008	*l*
	20 07	41.46	+ .033	*l*		12 26	38.15	+ .017	π
2273	17 03	20.76	+ .022	*l*		13 08	38.85	+ .032	*l*
2274	15 13	42.93	+ .041	*l*		13 17	39.00	+ .038	π
2276	16 04	22.96	+ .034	*l*		14 05	39.80	+ .024	*l*
	16 09	23.05	+ .037	π		14 14	39.95	+ .041	π
2280	17 36	51.68	+ .012	*l*		14 58	40.68	+ .030	*l*
	17 42	51.78	+ .022	π		15 06	40.81	+ .024	π
2282	16 06	29.37	+ .036	*l*		16 11	41.90	+ .034	*l*
	16 12	29.47	+ .033	π		16 18	42.01	+ .025	π
	16 46	30.03	+ .057	*l*		16 44	42.45	+ .022	*l*, 2
	16 52	30.13	+ .044	π	2353	13 27	10.24	− .004	*l*
	17 31	30.78	+ .016	*l*		13 35	10.38	+ .018	π
	17 36	30.87	+ .038	π	2354	13 05	33.87	+ .021	*l*
	18 18	31.57	+ .018	*l*		13 13	34.01	− .001	π
	18 25	31.68	+ .019	π		14 07	34.91	+ .003	*l*
	18 55	32.18	+ .011	*l*		14 13	35.01	− .026	π
	19 01	32.29	− .001	π		15 10	35.96	− .013	*l*
	19 31	32.78	+ .012	*l*		15 19	36.11	− .029	π
	19 37	32.88	.000	π	2363	15 30	45.82	+ .028	*l*
2296	15 17	20.46	+ .044	*l*		15 38	45.95	+ .021	π
	15 25	20.60	+ .035	π	2366	15 07	48.62	− .003	*l*, 4
2306	17 48	56.53	+ .035	*l*		15 09	48.65	+ .022	π
	17 56	56.67	+ .026	π	2386	14 47	46.53	+ .021	π, 2
2307	17 56	11.84	+ .014	*l*		15 07	46.87	+ .055	*l*, 2
	18 02	11.94	+ .019	π	2389	14 07	49.05	+ .056	*l*, 2
2312	15 10	60.26	+ .022	*l*, 2		14 15	49.18	+ .030	π, 2
	15 11	60.28	− .014	π	2391	13 31	27.63	+ .028	*l*
	15 48	60.89	+ .016	*l*		13 38	27.74	+ .021	π
	15 58	61.06	+ .017	π		14 06	28.21	+ .045	*l*, 2
2313	14 22	14.64	+ .028	*l*		14 13	28.33	+ .023	π, 2
	14 28	14.74	+ .036	π	2392	13 55	52.02	+ .039	*l*, 1
2317	12 35	40.04	+ .047	*l*		14 05	52.19	+ .037	π, 1
	12 42	40.16	+ .031	π					

NOTES

J.D. 2422265—Further measures stopped by clouds.

2312—Sky fair.

2313—Sky thick but uniform.

2354—Sky thick but uniform.

2363—Sky fair.

2366—Sky fair, measures discordant.

days or 104 periods. The epoch from the adopted correction of the last minimum is

$$\text{J.D. } 2422619.7866 \pm 0^{\mathrm{d}}.0003.$$

It will perhaps be worth while to observe one or more minima in this way each year, as the epoch can be determined with a probable error of less than one minute.

TABLE VI

OBSERVATIONS IN OCTOBER 1920

J.D. 242	G.M.T.	Difference of Magnitude	Computed Phase	Observed Phase	Correction to Ephemeris	Mean Correction
2599	$18^{\mathrm{h}}40^{\mathrm{m}}.4$	$-0^{\mathrm{M}}.734$	$+1^{\mathrm{h}}.24$	$+1^{\mathrm{h}}.62$	$-0^{\mathrm{h}}.38$	....
	18 50.3	−0.688	+1.45	+1.74	−0.29	....
	19 00.0	−0.618	+1.62	+1.93	−0.31	$-0^{\mathrm{h}}.33$
2616	19 09.1	−0.334	−3.10	−2.80	−0.30	....
	19 20.3	−0.377	−2.91	−2.65	−0.26	....
	19 32.0	−0.430	−2.71	−2.47	−0.24	−0.27
2619	17 31.2	−0.870	−1.50	−1.26	−0.24	....
	17 42.2	−0.944	−1.36	−1.07	−0.29	−0.26
	17 54.4	−1.004	−1.16	−0.89	−0.27	....
	18 07.2	−1.068	−1.06	−0.73	−0.33	....
	18 19.6	−1.142	−0.74	−0.47	−0.27	−0.29
	18 34.6	−1.188	−0.45	....	....	....
	19 08.2	−1.170	+0.07	....	....	....
	19 19.4	−1.122	+0.26	+0.55	−0.29	....
	19 33.4	−1.056	+0.50	+0.77	−0.27	....
	19 49.6	−0.966	+0.76	+1.02	−0.26	−0.27
	20 03.6	−0.837	+0.99	+1.34	−0.35	....
	20 14.8	−0.804	+1.18	+1.43	−0.25	....
	20 27.2	−0.680	+1.39	+1.76	−0.37	−0.32
	20 38.0	−0.622	+1.57	+1.92	−0.35	....
	20 49.5	−0.558	+1.76	+2.09	−0.33	−0.34

As the measures of Table VI were made after the computations of this paper were finished, they were not used further. The three observations beginning with $18^{\mathrm{h}}19^{\mathrm{m}}.6$ on J.D. 2422619 are all within a half-hour of minimum, and give residuals from the final light-curve of $+0^{\mathrm{M}}.004$, $+0^{\mathrm{M}}.003$, and $-0^{\mathrm{M}}.006$ respectively, or a mean of $0^{\mathrm{M}}.000$, which shows that as far as accidental error is concerned the lowest point of the curve is well determined.

Table VII gives the normal magnitudes formed in the usual way from the observations in Tables IV and V. The residuals were formed from the final light-curve. Except near the time of greatest eclipse at primary, the number of sets in each normal are nearly enough equal so that all normals may be given the same

weight. The number of nights in a normal is presumably more important than the number of sets. The normals of Table VII together with the light-curves of the 1920 and 1910 series are shown in Figure 1.

TABLE VII

NORMAL MAGNITUDES

Phase	Difference of Magnitude	Residual O−C	Sets	Phase	Difference of Magnitude	Residual O−C	Sets
−4^{h}32	−0^{M}052	−0^{M}012	6	5^{d}06	+0^{M}004	+0^{M}002	8
−3.94	−0.118	− .026	8	5.49	− .002	− .005	8
−3.51	−0.166	.000	8	5.94	+ .002	− .001	8
−3.02	−0.289	− .011	8	6.44	.000	− .005	8
−2.70	−0.372	− .009	8	10.31	+ .007	− .007	6
−2.36	−0.462	+ .004	8	11.89	+ .016	− .002	6
−2.10	−0.563	− .008	8	14.40	+ .023	.000	9
−1.74	−0.682	+ .005	8	20.61	+ .034	+ .002	9
−1.48	−0.793	− .008	6	23.00	+ .036	+ .003	6
−1.26	−0.868	+ .002	6	23.92	+ .036	+ .003	6
−0.92	−0.979	+ .023	4	27.68	+ .024	− .008	6
−0.57	−1.099	+ .019	4	28.27	+ .034	+ .002	4
−0.33	−1.168	+ .001	4	29.62	+ .042	+ .010	9
+0.02	−1.200	.000	4	30.59	+ .033	+ .006	9
+0.40	−1.154	+ .003	4	31.81	+ .016	+ .002	9
+0.90	−1.020	− .011	4	32.65	+ .004	− .002	9
+1.16	−0.917	− .007	4	33.76	+ .001	+ .008	7
+1.49	−0.766	+ .016	6	35.11	− .011	.000	9
+1.72	−0.688	+ .007	6	35.97	− .016	− .013	9
+1.95	−0.603	+ .007	6	36.60	+ .004	.000	6
+2.19	−0.514	+ .009	8	38.22	+ .029	+ .006	9
+2.44	−0.433	+ .008	8	38.88	+ .038	+ .009	9
+2.66	−0.376	− .001	8	39.90	+ .032	.000	9
+2.90	−0.304	+ .005	8	40.19	+ .033	+ .001	9
+3.17	−0.232	+ .008	8	40.79	+ .031	− .001	9
+3.47	−0.175	− .001	8	41.47	+ .032	.000	9
+3.80	−0.106	+ .008	8	42.46	+ .029	− .003	8
+4.07	−0.075	− .001	6	46.10	+ .023	− .010	8
+4.36	−0.031	+ .004	6	48.05	+ .025	− .007	8
+4.69	−0.009	− .003	6	49^{h}97	+ .033	+ .002	7
				51.94	+ .030	+ .002	5
				56.60	+ .030	+ .012	6
				60.13	+ .018	+ .008	8
				60.74	+ .006	− .002	9
				63.12	+ .013	+ .010	6
				63.87	− .006	− .008	6

DETERMINATION OF THE ELEMENTS

After a graphical solution had been made for the time of primary minimum, so that the final phases could be computed,

the next step was to use the observations between minima for a determination of the radiation-effect and ellipticity of figure. The 1910 observations had indicated a conspicuous rise in the light from primary to secondary, but no measurable maximum at phase $\pi/2$ due to elongation of the components of the system. The more accurate new series, however, shows that it is worth while to include in the solution the ellipticity term. Using thirteen normals following primary and fourteen following secondary, there was found by least-squares

TABLE VIII

COMBINED NORMALS, PRIMARY MINIMUM

Phase	Difference of Magnitude	Rectified Light	Residual in Light	No. of Sets
0^h02	-1^M200	0.352	0.000	4
0.33	−1.168	.362	+ .001	4
0.40	−1.154	.366	+ .001	4
0.57	−1.099	.384	+ .007	4
0.91	−1.000	.417	+ .002	8
1.21	−0.892	.458	− .001	10
1.48	−0.780	.504	+ .002	12
1.73	−0.685	.547	+ .002	14
2.02	−0.583	.597	− .001	14
2.28	−0.488	.649	+ .001	16
2.55	−0.404	.699	.000	16
2.80	−0.338	.741	.000	16
3.12	−0.251	.800	.000	12
3.48	−0.172	.858	.000	12
3.94	−0.096	.918	− .003	18
4.33	−0.045	.961	− .003	9
4.77	−0.008	.991	− .007	9

$$\text{Difference of magnitude} = \underset{\pm 15}{0^M\!.0285} - \underset{\pm 11}{0^M\!.0164} \cos\theta - \underset{\pm 27}{0^M\!.0148} \cos^2\theta, \quad (1)$$

where θ is the phase-angle, and the probable errors were computed in the usual way, the probable error of a single normal being $\pm 0^M\!.0039$. The coefficient of $\cos^2\theta$ gives for the ellipticity constant $z = 0.027$.

The solution was made by Russell's method. The normals at primary minimum before and after zero phase were combined on one branch of the curve, and the resulting combined normals were rectified by adding $+0^M\!.0148 \cos^2\theta$ to the observed magnitudes, then reducing to light and adding $0.0149\ (1+\cos\theta)$ in light units. The result and the residuals are in Table VIII. There are fewer

observations in the half-hour near zero phase, but these residuals are not unduly large.

The constants of the rectified curve are given in Table IX.

The time of secondary minimum cannot be determined with great accuracy, but nevertheless even with a variation of only

TABLE IX

RECTIFIED CURVE

	Magnitude	Range	Light	Loss of Light
Maximum................	+0.045	....	1.000	....
Primary minimum.........	−1.089	1.134	0.352	0.648
Secondary minimum.......	+0.003	0.042	0.962	0.038

$0^{M}04$ this test of the ellipticity of the orbit is more delicate than that by any other method. The phase of secondary was determined graphically, and tabulating the comparison with previous results we have:

TABLE X

PHASE OF SECONDARY MINIMUM

Light-curve, 1920	$34^{h}65$
Light-curve, 1910	34.67
Spectroscopic, $e=0.05$	36.46
Assumed, $e=0.00$	34.41

The close agreement with the previously observed time is largely accidental, but there is once more no photometric evidence of any considerable orbital eccentricity, and for the purposes of this paper the orbit may be considered circular.

In 1910 the elements of Algol were determined with no allowance for possible light of the third body, but with the known third component of long period it is evident that we have here a case similar to that of λ Tauri, and the computed elements will depend upon how much of the light of the system comes from the distant satellite. I learn from Dr. Schlesinger that he has in hand a study of the Allegheny spectrograms which show additional lines at primary minimum; if these lines are due to the third body it may be possible to determine the actual masses of the three components, and to estimate the light of the third body. For

the present it will be sufficient to determine the elements, neglecting the third body's light, $L_3=0$, for comparison with the 1910 results, and then to indicate the influence of L_3.

Using Russell's method and notation for partial eclipse of uniform disks it was found that a satisfactory light-curve is given by $C=0.0935$, $D=0.0500$, $\chi=1.870$. Carrying through the solution for the elements, and arranging the 1910 results in the same form for comparison, we have:

TABLE XI

ELEMENTS OF THE ECLIPSING SYSTEM

		1920	1910
Ratio of radii	k	0.85	0.88
Area of bright body obscured at minimum	α_0	0.700	0.711
Light of bright body	L_b	0.925	0.898
Light of bright side of faint body	L_f	0.075	0.102
Light of fainter side of faint body	L_f-2b	0.045	0.058
Ratio of surface brightness of bright sides of bodies	J_f/J_b	0.059	0.088
Radius of bright body, radius of orbit = 1	a_b	0.207	0.210
Radius of faint body, radius of orbit = 1	a_f	0.244	0.239
Cosine of inclination	$\cos i$	0.142	0.134
Ellipsoidal constant	z	0.027	0.0
Ratio of axes of ellipsoids	b/a	0.987	1.0
	c/a	0.978	1.0
Mean density of system, sun = 1	ρ_0	0.07	0.07
Duration of eclipse	....	$9^{h}66$	$9^{h}80$
Albedo, Lambert's law	μ_1	0.7	1.1
Albedo, Seeliger's law	μ_2	1.0	1.5

A comparison of the elements shows that there is little difference between the two series, except for the ellipticity of figure detected in 1920, and the smaller light measured for the fainter component. The selenium photometer gave practically the same color-sensitivity as visual measures, whereas the color-equation of the photo-electric installation is 0.70 magnitude. The intensity of the bright side of the companion in the new series is 0.059, whereas it was 0.088 with selenium. These two values, which correspond to the secondary minima of $0^{M}04$ and $0^{M}06$ respectively, show that the companion compared with the primary of spectrum B8 was measured only two-thirds as bright in photo-electric as in visual light, which would indicate a spectrum of approximately G0. If we had observations of sufficient precision, and also could allow for the light of the third component of the system, the

determinations of the light of the two sides of the fainter body with instruments of different color-sensitivity would give a rough measure of the color-index, and hence of the spectrum of each side of the faint star. In the present case, however, I doubt if we can say more than that the satellite is a yellower star than the primary.

As in the case of λ Tauri,[1] the solution for partial eclipses is given by the intersection of the two curves,

$$\chi(k,\ \alpha_0,\ \tfrac{1}{4})=\text{constant},$$

$$\alpha_0=\frac{1}{1-L_3}\left(1-\lambda_1+\frac{1-\lambda_2}{k^2}\right),$$

where the introduction of L_3 into the last equation takes account of the third body. The larger the value of L_3, the greater is the area of eclipse at primary minimum, and the smaller is the bright body compared with the eclipsing satellite. An upper limit of L_3 is given, however, by the fact that its light may not show even when the total light of the system is reduced 1.2 magnitudes at minimum, or to one-third of the light at maximum. It is just here, however, that the additional spectrum lines at primary minimum may give an estimate of the light of the third body. It is not probable that L_3 is much greater than 0.10, which would give it nearly one-third of the total light at minimum. This would reduce the computed relative radius k to 0.78, as compared with $k=0.85$ shown in Table XI for $L_3=0$. It is obvious that with the light of the third body undetermined only rough elements for Algol can be found, but the uncertainty for this system is no greater than for any other of the many eclipsing stars where there may happen to be unknown additional companions.

All of the computations in this paper are based upon assumed uniform intensity of the apparent disks of the components of Algol. In view of the satisfactory agreement of the observations with the computed light-curve, and the uncertain influence of the third body. it has not seemed worth while to consider the additional complication of darkening at the limb.

In Table XII is the final light-curve of 1920 computed from the elements in Table XI, together with a comparison with the

[1] *Astrophysical Journal*, **51**, 211, 1920.

curve of 1910. To make the comparison, the printed difference of magnitude of 1910 have been changed in sign, and $0^M.174$ has then been added to make the average magnitude between eclipses the same for the two series. The average difference between the two curves in the table is $0^M.006$, which depends however, upon

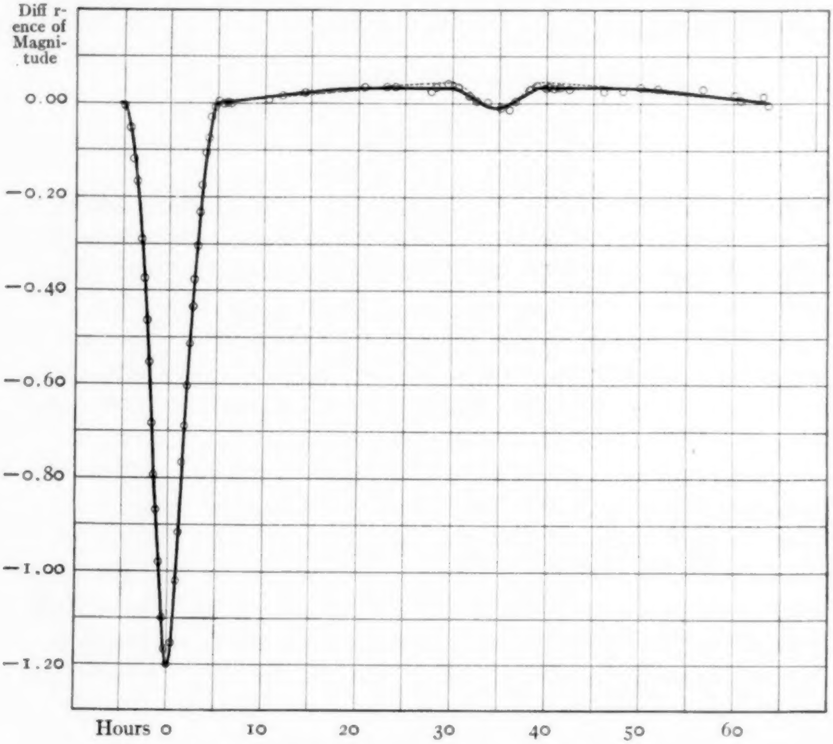

Fig. 1.—Light-curve of Algol. Heavy line, 1920; broken line, 1910

the number of points selected during and between the eclipses. With the forced agreement at maximum, the difference at greatest eclipse is $0^M.004$. The two curves are shown in Figure 1, where on the scale used the same line represents the two curves during primary minimum; this is rather remarkable inasmuch as the adjustment between the curves was made outside of the eclipses, and previous observers have found considerable differences in the forms of the light-curves taken in different colors. Any difference

in the epoch of minimum as derived in light of different wave-lengths would not show in this comparison of series not taken simultaneously.

TABLE XII

LIGHT-CURVES OF ALGOL

Phase	1920	1910	Difference	Phase	1920	1910	Difference
± $0^{h}0$	$-1^{M}200$	$-1^{M}196$	$-0^{M}004$	$30^{h}0$	$+0^{M}031$	$+0^{M}045$	$-0^{M}014$
± 0.5	−1.135	−1.136	+ .001	31.0	+ .023	+ .036	− .013
± 1.0	−0.972	−0.976	+ .004	32.0	+ .012	+ .022	− .010
± 1.5	− .778	− .776	− .002	33.0	.000	+ .004	− .004
± 2.0	− .592	− .596	+ .004	34.0	− .010	− .012	+ .002
± 2.5	− .422	− .436	+ .014	34.65	− .012	− .015	+ .003
± 3.0	− .283	− .296	+ .013	35.0	− .011	− .014	+ .003
± 3.5	− .168	− .176	+ .008	36.0	− .003	− .003	.000
± 4.0	− .084	− .091	+ .007	37.0	+ .009	+ .014	− .005
± 4.5	− .021	− .026	+ .005	38.0	+ .021	+ .032	− .011
± 4.83	+ .002	.000	+ .002	39.0	+ .031	+ .043	− .012
+ 5.0	+ .002	.000	+ .002	39.48	+ .031	+ .046	− .015
10.0	+ .012	+ .008	+ .004	40.0	+ .032	+ .046	− .014
15.0	+ .024	+ .018	+ .006	45.0	+ .033	+ .038	− .005
20.0	+ .032	+ .030	+ .002	50.0	+ .031	+ .027	+ .004
25.0	+ .033	+ .040	− .007	55.0	+ .022	+ .016	+ .006
29.82	+ .031	+ .046	− .015	60.0	+ .010	+ .006	+ .004

A test of the accuracy of the present measures is given by the residuals in Table VII, from which the comparison with 1910 is made in Table XIII. The weight of the determination of a light-

TABLE XIII

PROBABLE ERRORS AND WEIGHTS

	1920	1910
Number of normals at primary minimum	30	20
Probable error of one normal	$0^{M}007$	$0^{M}023$
Relative weight of determination	16.2	1
Number of normals at secondary and between minima	36	24
Probable error of one normal	$0^{M}004$	$0^{M}006$
Relative weight of determination	3.4	1
Relative weight of complete curve	4	1

curve may be taken as proportional to n/r^2, where n is the number of normals and r the probable error of each.

It is thus seen that the photo-electric measures give a curve which, when compared with the selenium curve, has sixteen times the weight at minimum, more than three times the weight at maximum, and about four times the weight for the whole curve. Also

it is to be noted that in the new series the light of Algol was cut down with a shade-glass, fivefold at minimum and thirteen fold at maximum. The observing time was less in 1920 than in 1910, perhaps a fair estimate being that the new curve represents half the effort of the old one. The selenium measures are therefore quite superseded, and no doubt after another ten years, if not before, someone else or myself will be able to improve upon the present results.

There has been only one parallax of Algol published since 1910, that from Yerkes, $+0''.020 \pm 0''.014$, and until there are several more modern photographic determinations available, it seems scarcely worth while to recompute the total light and surface brightness of the components. Dr. Schlesinger has sent me a value of $\pi = 0''.032$ for the absolute parallax, from the results of Chase, Russell, and Yerkes. This is 10 per cent larger than the parallax, $0''.029$, quoted at the end of my previous paper, and would make the total light of Algol about two hundred times that of the sun. This with a plausible assumption as to the ratio of the masses would give the companion a surface intensity ten times that of the sun, which value is presumably rather high for the spectrum G, estimated from the secondary minimum. It is evident that we need the best parallax that can be determined by several observers.

Therefore, in spite of the increased accuracy over the former work, the present photometric measures cannot give definitive results for the system. If the spectrum of the third body can be measured, its light estimated, and also the parallax determined with a small relative error, then, as it has been said, we shall know "all about Algol."

I am indebted to Mr. C. C. Wylie for some of the observations toward the end of the 1920 series, and to Miss Iva Hamlin for many of the reductions. The present satisfactory performance of the photometer is due largely to Dr. Elmer Dershem, who rebuilt most of the instrument during the summer of 1919.

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University of Illinois Observatory
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AN EXAMINATION OF THE INFRA-RED SPECTRUM OF THE SUN, λ 8900–λ 9900[1]

By FREDERICK S. BRACKETT

ABSTRACT

Photography of infra-red spectra to λ *9900.*—In previous work scattered light has been a serious obstacle to the extension of observations into the infra-red. By using a monochrometer with the second slit removed the author *eliminated scattered light* and obtained, on plates sensitized with dicyanin, spectrograms of even intensity which show fine structure to λ 9850. This limit seems to be fixed in astronomical work by Langley's broad atmospheric absorption band ϕ. Below λ 9400 a *water solution of malachite green* is recommended as a *screen* since it is almost opaque to wave-lengths shorter than λ 7200.

Infra-red solar spectrum λ *8900 to* λ *9900.*—Spectrograms made in the first order of a 15-foot concave grating mounted in the constant temperature pit of the Mount Wilson laboratory gave the *wave-lengths* of 563 lines to about 0.01 A, at least as far as λ 9650 (Table I). To determine the *origin* of the lines, solar-rotation photographs were made with the 13-foot spectrograph of the 60-foot tower telescope, and spectrograms taken under conditions of low and high humidity were compared. It was found that 45 and possibly 70 lines, including one-fifth of the fainter lines observed, are of solar origin, while 60 of the stronger diffuse telluric lines broaden remarkably as the humidity increases and hence undoubtedly form an *absorption band due to water vapor between* λ *9300 and* λ *9650*. Of the solar lines, 14 are attributed to *iron* and 1 or 2 to *nickel*.

The investigator is naturally attracted to the less refrangible end of the spectrum by the fact that the characteristic displacements due to some of the most interesting spectroscopic phenomena increase with increasing wave-length, among them being the Doppler effect, the Zeeman effect, pressure shift, and the possible Einstein effect. But before work of precision can be done in any region, it is desirable, if not absolutely necessary, to make some preliminary survey of the field. In the case of the infra-red spectrum of the sun the work of Dr. Meggers, which he has been kind enough to furnish the Mount Wilson Observatory in advance of publication, gives identifications and wave-lengths down to 9000 A, and it is the purpose of the present investigation to extend these results as far as can readily be done with dicyanin-bathed plates.

Since Dr. Meggers published his map of the solar spectrum from 6800 A to 9600 A,[2] frequent attempts have been made to extend

[1] *Contributions from the Mount Wilson Observatory*, No. 197.

[2] *Astrophysical Journal*, **47**, 1, 1918.

the limit to still longer wave-lengths by photography with plates bathed in dicyanin, but until recently the attempts have met with little success. In March of this year Dr. K. Burns[1] published his photographs showing the more outstanding structure to almost 9900 A. On all of these plates, however, much of the finer structure beyond 9200 A appears to have been lost. That the chief cause of this lack of contrast is scattered light there can now be little doubt. When the present investigation was first undertaken, it was believed that the chief difficulty was the loss of defining power in the lenses, due to a rapid change in the properties of the glass with increasing wave-length. But the appearance of a ghost of the B group between 9600 A and 9700 A on a plate taken with the 13-foot spectrograph of the 60-foot tower telescope seemed to prove that the presence of scattered light was responsible.

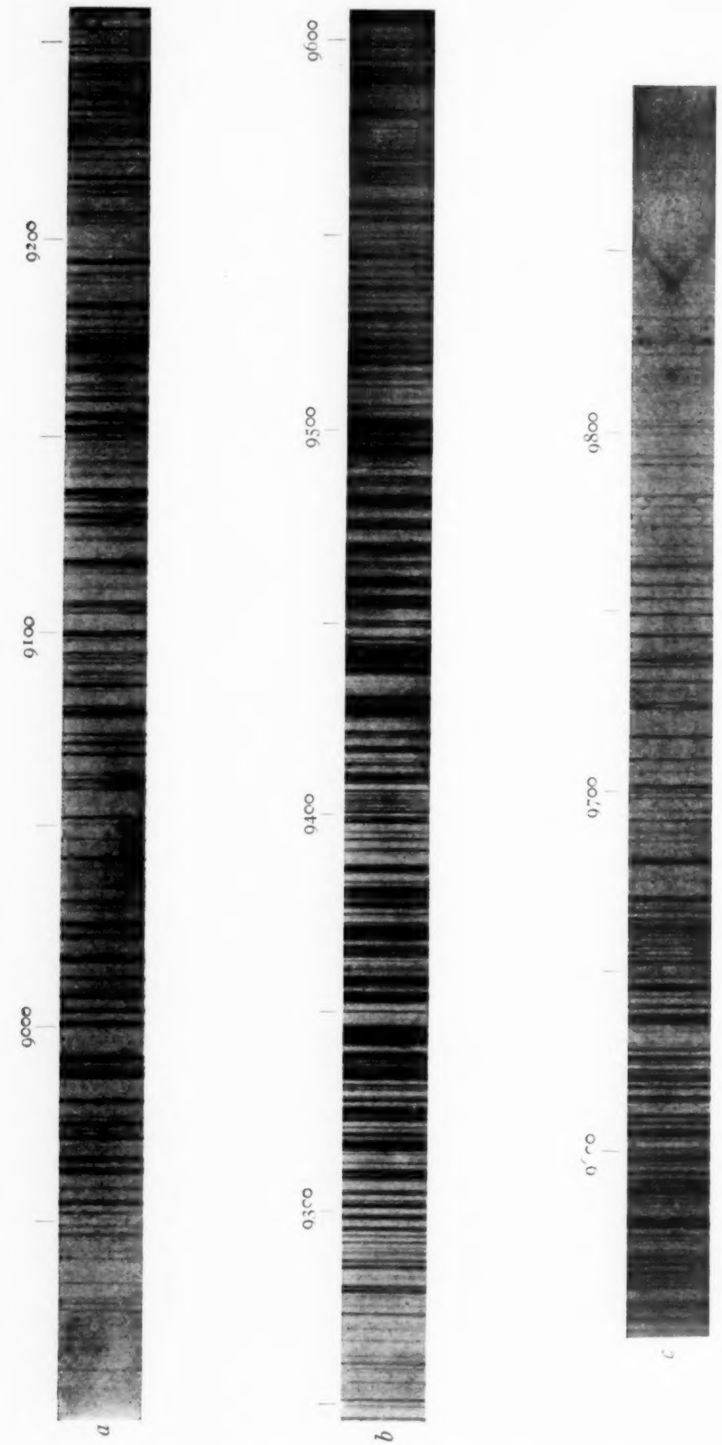
In order to establish this fact with certainty, a series of tests was made in the laboratory with a one-meter concave grating. Exposures were first tried with a screen opaque to wave-lengths shorter than 6400 A. On these plates the contrast fell off rapidly beyond 9200 A, until even the strongest lines were lost at 9600 A. Exposures were then made through a water solution of malachite green. A screen more than a centimeter in thickness proved almost opaque to all wave-lengths shorter than 7200 A. Photographs taken with this screen were much superior to those previously obtained and showed lines well beyond 9750 A. For infra-red work at wave-lengths shorter than 9400 A this type of screen may be strongly recommended.

As screens opaque to still longer wave-lengths, and at the same time transparent beyond 9000 A, were not available, the only possibility of further progress lay in preliminary analysis. For this purpose a Hilger monochrometer with the second slit removed was set in collimation with the spectrograph. It was found that when the first slit of the monochrometer was open about two millimeters, light extending over several hundred angstroms was admitted to the slit of the spectrograph.

By calibrating the screw of the monochrometer, settings could be made which would admit any desired range of spectrum.

[1] *Lick Observatory Bulletins*, No. 327, 1920

PLATE I



INFRA-RED SPECTRUM OF THE SUN, λ8000–λ9900

Moreover, this adjustment could be changed during the exposures, so that the intensity could be adapted to the sensitiveness of the plate for a given wave-length. This made it possible, even in the extreme infra-red where the sensitiveness falls off rapidly, to obtain photographs of even density throughout a long range of spectrum. Plates made with this arrangement showed sharply defined lines as far as the slightest trace of continuous background could be detected.

The monochrometer was used with a 15-foot Anderson concave grating in a Rowland mounting placed vertically in a constant temperature pit, and photographs were taken which show the fine structure to 9800 A. The first order of the grating was used, giving a scale of about 3.7 A to the millimeter. Although the grating proved quite fast, the system was optically slow; the aperture ratio was $f/45$ and much of the light was lost because of the astigmatism characteristic of the Rowland mounting, when used at the large angle necessary for the infra-red, even in the first order.

The best dicyanin at hand at the time the investigation was begun was of old German stock, which proved slightly superior to that obtained from the Bureau of Chemistry of the Department of Agriculture. Exposures ranged from seven to twenty-one hours, extending over as many as three days. This is the most rigorous test to which the mounting in the constant temperature pit has been subjected and proves clearly its merit, since even these long exposures show practically no loss of definition. The longest exposure reveals lines to almost 9900 A; the portion of the spectrum between 9600 A and 9900 A shown on this photograph is reproduced in Plate I*c*.

In February of this year, however, a shipment of dicyanin labeled A VI–8 was received from the Bureau of Chemistry which proved much faster than anything previously used. Photographs on bathed Seed 23 plates were obtained in seven hours which showed lines beyond 9800 A.

In order to determine the wave-lengths of lines which could be used as a basis for the reduction of the plates, exposures were made on the same plate to the second-order iron arc and to the first-order infra-red solar spectrum. The light from the arc was

thrown directly upon the slit by two small prisms on either side of the beam from the monochrometer. Because of astigmatism, however, all the lines extend entirely across the plates. All screening arrangements near the plate were avoided on account of the danger of moving the plate-holder. The arc exposure was made in five parts, distributed symmetrically throughout the solar exposure. The illumination of the grating by both arc and sun was carefully adjusted, so that any possible displacement due to differences in illumination would presumably be small. As the grating used is one of the most perfect, the coincidence of the two orders can be subject to little question. The two plates obtained agreed perfectly. It is to be regretted, however, that lack of time prevented checking them by a different set-up. In measuring these plates all lines were avoided which showed any suggestion of blend.

The rotation plates for the separation of the solar and telluric lines were taken with the 13-foot spectrograph of the 60-foot tower telescope, which projects an image of the sun about 6.7 inches in diameter. Although lenses are used in both collimator and camera of the spectrograph, it was found that a fair focus could be obtained over the whole region. The chief difficulty in the work proved to be the many adjustments necessary for both the monochrometer and the spectrograph. The 13-foot spectrograph is a two-lens system with one reflection, and the grating is set at a considerable angle, so that the dispersion is considerably greater than normal, thus giving a scale in the infra-red of the first order of 3.3 A to the millimeter. Although the aperture ratio of the system is limited by the telescope to $f/60$, being non-astigmatic, it proved over twice as fast as the 15-foot concave grating.

Because of the already complicated optical system, the use of prisms to unite the beams from the limbs of the sun was not attempted. A simple exposing screen in front of the slit was used. The exposure for one limb was made in two parts, one before and one after the exposure for the other limb, so that any mechanical shift would not introduce a displacement.

Photographs of the spectrum of the center of the sun were also taken, in order to determine the wave-lengths of the solar lines. As these plates were taken in the middle of August, a correction of

+0.009 A had to be added because the earth was then approaching the sun. Inasmuch as the period of exposure was longer in the afternoon than in the morning, a slight correction, −0.002 A, had to be subtracted. A total correction of +0.007 A has therefore been applied to all solar wave-lengths.

Fortunately, plates were secured at times of both high and low humidity. An examination of these plates on a comparator showed beyond 9300 A a remarkable broadening of the lines on photographs taken during high humidity, which is entirely independent of exposure time, appearing alike on plates of different densities. As the mean altitude of the sun was about the same for all exposures, there can be little doubt that this effect is due to water-vapor. In the list of wave-lengths only those lines which showed the most marked effect have been attributed to water-vapor, although it is quite likely that others than those so designated are due to this source.

The reduction of the rotation plates showed roughly 10 per cent of the five hundred lines measured to be of solar origin. Of these, fourteen may be attributed to iron and possibly one or two to nickel. In the region between 9300 A and 9650 A over sixty broad diffuse lines appear which are due to water-vapor.

In measuring the plates the chief emphasis has been laid on consistency. The wave-lengths recorded represent measures made on from two to eight plates. In the region from 9000 A to 9650 A the wave-lengths should be reliable to less than ±0.01 A, except where the line is marked with an "a." Beyond 9650 A the wave-lengths are determined by extrapolation, and systematic errors may enter.

On the first plates obtained intensities were estimated between 00 and 10, but on the later plates showing both fainter and broader lines, they were classified between 000 and 12. In the case of the water-vapor lines this classification is not altogether satisfactory, since at times of high humidity some of them extend over several angstroms. These lines also present special difficulty in measurement, not only because of their broad diffuse character, but also because they do not widen symmetrically with increasing humidity. Their wave-lengths are merely approximate.

TABLE I

λ	Intensity	Source Element	λ	Intensity	Source Element
9000.45	7B		9100.60	1	*A*, *S*, Fe
9003.81	6		9105.47	3	
9007.02	0	*S*	9106.30	0	*S*, Ni
9007.63	1		9107.06	0 U	
9008.57	000	*S*	9107.42	1	
9009.09	0		9108.41	1V	
9009.88	00	*S*	9110.57	000	*S*
9010.57	000	*S*	9111.92	0	*S?*
9011.95	4		9113.04	00	
9016.80	5		9114.50	000	*S*
9018.12	0		9115.73	0	
9021.68	000	*S*	9117.08	0R	
9022.71	4		9118.09	1	
9024.53	000	*S*, Fe	9118.98	3	
9025.97	4		9124.37	0	*S*
9029.45	0		9124.93	00	
9031.47	2		9127.87	1	
9034.98	00		9128.65	1	
9040.16	0		9129.90	1	
9041.20	000		9130.70	3	
9042.32	00		9132.53	1	
9042.88	1		9134.36	1	
9047.46	0		9134.87	0	*S?*
9048.62	000		9136.07	1	
9051.18	00		9136.64	3	
9053.03	2		9137.12	1	
9060.49	1		9139.89	000	
9061.52	00	*S*	9140.55	0	
9061.87	00		9141.14	00	
9062.77	1		9142.77	00	
9064.08	1		9143.55	00	
9069.20	4		9144.22	0	
9070.43	000	*S*, Fe	9144.64	00	
9072.03	5		9145.79	000	
9073.20	00		9146.25	0	*S*, Fe
9074.36	3		9147.05	000	*S*
9078.33	00	*S*, Ni?	9148.02	00	*S*, Fe
9079.13*a*	00		9148.78	00	
9079.84*a*	1	*A*, *S*, Fe	9150.12	1	
9080.57	00		9150.88	0	
9081.37	3		9151.85	0BR	
9085.50	00	*S*, Ni?	9152.69	2	
9086.71	2		9153.24	2	
9087.08	4		9154.23	000	*S*
9088.49	0	*S*, Fe	9155.68	6BR	
9089.55	00	*S*, Fe	9156.93	0	
9089.94	0		9160.15	1	
9090.42	00		9160.97	1	
9092.58	1		9162.69	0V	
9093.85	1		9164.05	0BR	
9095.01	1	*S*	9167.38	00	
9095.38	0		9168.01	1	
9098.52	0		9168.88	0	*S?*
9099.83	2		9169.43	0	

TABLE I—*Continued*

λ	Intensity	Source Element	λ	Intensity	Source Element
9170.78	00	....	9251.19	2	....
9171.76	00	....	9252.53	00	*S*
9172.58	0	....	9253.23	00	*S*
9172.97	00	....	9253.84	00	*S*
9173.06	0	....	9254.44	0	....
9174.23	3	....	9255.29	00	*S?*
9175.31	2	....	9255.87	1	*S*
9176.97	3	....	9257.01	00	....
9178.62	1	....	9258.36	0	*S*, Fe
9179.39	000	....	9259.17	0	*S?*Fe
9181.30	1	....	9260.45	1	....
9182.15	000	....	9261.06	00	....
9183.59	00	....	9261.67	00	....
9184.48	2	....	9262.35	0	....
9185.06	2	....	9263.16	00	....
9186.56	00	....	9263.97	000	*S*
9190.33	0	....	9266.26	1	....
9191.71	00	....	9267.22*a*	00	....
9192.67	2	....	9269.17	0	....
9195.46	2	....	9270.14	00	*S?*
9196.12	2	....	9270.88	00	*S?*
9199.20	00	....	9272.30	0	....
9205.69	0	....	9273.14	2	....
9206.93	0	....	9274.32	00	....
9207.90	0	....	9275.16	0	....
9208.70	0	....	9275.80	00	....
9210.09	0	*S*, Fe	9276.31	000	....
9212.92	2	....	9276.92	00	....
9214.74	3	....	9277.60	0	....
9215.70	00	....	9278.91	4	....
9217.35	4	....	9279.83	1	....
9218.36	00	*S*	9280.21	0	....
9222.10	0	....	9281.99	0	....
9225.10	2	....	9282.78	0	....
9228.19	00	*S*	9284.22	00	....
9228.76	00	....	9284.98	2	....
9229.70	00	....	9285.70	00	....
9230.58	00	....	9286.53	1	....
9232.84	1	....	9286.90	0	....
9234.85	1	....	9288.09	000	*S*
9235.30	00	....	9288.60	00	*S?*
9235.83	00	....	9288.98	00	*S?*
9237.49	0	*S*	9289.95	0	*S?*
9238.18	1	....	9290.59	00	*S*
9239.07	1	....	9291.43	3	....
9240.03	000	*S*	9292.78	0	....
9240.45	00	....	9293.23	1	....
9242.33	00	*S*, Fe	9294.56	2	....
9243.10	0 U	....	9295.21	3	....
9243.41*a*	00	....	9296.50	00	....
9244.53 44.74	1 2D	....	9297.23	00	....
9244.93	1	....	9297.80	4	....
9246.41	3	....	9298.70	0	....
9249.57	0	....	9300.53	3	....

TABLE I—*Continued*

λ	Intensity	Source Element	λ	Intensity	Source Element
9301.14	2		9357.55a	6-9 U	w
9301.98	2		9358.93a	5-8	w
9302.77	00		9360.24	000	
9303.92	4		9360.60	00	
9304.66	1		9361.28	2	
9305.48	00		9361.93	00	
9306.34	00		9362.33	0	S, Fe
9307.30	1		9363.39	1V	
9308.14	4		9364.95a	4-8	w
9308.97a	0		9366.46a	5 10	w
9309.62	5-9	w	9367.41	1B	
9310.91a	00		9369.60a	5-9	w
9311.80	2		9371.58a	7B-12B	w
9312.72	000		9373.14	2	
9314.08	1		9374.34	0	
9315.21	3		9375.28	3	
9316.11a	4-8 U	w	9375.74	00*	
9319.14a	5-9	w	9377.74a	7-11	w
9320.12	0		9379.74a	3-5	w
9320.83a	4-6	w	9381.22a	7-11 U	w
9321.76	00		9382.22	2	
9322.55	3		9383.63	2	
9323.20	3		9385.84a	00	
9324.24	3-		9386.84a	7-11	w
9325.06a	1 -9D	w	9387.91	3	
9325.67a	4	w	9390.88	0	
9326.71a	00		9391.84	3	
9327.82	4		9394.43	3	
9328.80	1		9396.32	2	
9329.93	00		9400.18	2	
9330.53	1		9401.68	3BV	
9331.52	2		9402.67	1	
9333.55a	5-8 U	w	9403.31	00	
9334.64a	4-7	w	9404.51	1	
9335.69	0		9405.30a	00	
9336.13	1		9405.78	00B	A, S?
9337.23	3		9406.96	3	
9337.88	0		9408.00	00	
9338.52	2		9409.10	3	
9339.47a	5-8	w	9410.44a	5-8	w
9342.52a	6-8	w	9411.38	1_0	S?
9344.05a	9D-12 U	w	9411.91	0	
9345.67a	6-8	w	9412.75	1	
9346.98	2		9413.55	2	A,S?
9347.70	0	S?	9414.10	2	A,S?Fe?
9348.46	1		9415.07	1	S
9349.31	00		9416.08	00	
9350.52	3		9416.87	0	S
9352.01	00		9417.72a	4-7	w
9353.06a	3-5	w	9420.09	00	
9353.65a	3-4 U	w	9420.81	0	
9354.50a	5-7	w	9421.90	4	
9355.26a	1-3	w	9424.89	0	
9356.58	1		9426.85a	7-11 U	w
			9428.36a	7-10	w

TABLE I—*Continued*

λ	Intensity	Source Element	λ	Intensity	Source Element
9430.68*a*	5V–8V	*w*	9500.76*a*	6} –12D	*w*
9432.03*a*	000	*S?*	9501.71*a*	4}	*w*
9432.85	00	*S*	9503.30	00B	
9434.97	00		9504.51	1	
9437.90*a*	7–10 Wings	*w*	9505.68	3B	
9440.89*a*	10D–14D	*w*	9506.81	00	
9442.48	1		9507.82	0B	
9443.39*a*	3–5	*w?*	9508.86	0B}	
9444.47	2		9509.38	00}	
9446.08	4		9510.83	2	
9447.13	00		9512.69	1	
9449.22	2		9513.82	1	
9450.38	3		9514.55	1	
9452.65	00		9516.35*a*	1}	
9454.12*a*	3–5}	*w?*	9517.06*a*	6} –12U	*w*
9454.79*a*	3–5}	*w?*	9518.05	1}	
9456.22*a*	4–7	*w*	9519.34*a*	3–5}	*w*
9456.98*a*	0–2	*w?*	9520.04*a*	0}	
9459.96*a*	6–10	*w*	9520.62	00	
9461.16*a*	7–11	*w*	9522.30*a*	7–12	*w*
9463.03	00		9523.62	1	
9464.05	0		9525.16	4	
9464.88	1		9526.91	00	
9465.52	2		9527.60	1	
9467.12	1		9528.53	3BR	
9467.90	1		9529.51	2	
9468.68	2		9531.30	0	
9469.50	3		9531.79	1	
9470.57	2		9533.48	1	
9471.63	000	*S?*	9535.00	00B	
9472.51	00		9536.12*a*	4–6	*w*
9473.14	00B		9538.47	4	
9474.36	5B} U		9540.98	5	
9475.27	3}		9543.93*a*	6–11D	*w*
9476.07	2		9544.61	2	
9476.85	2		9545.92	1	
9478.99	00		9546.63	0	
9480.23*a*	5–7	*w*	9547.15	00	
9481.97*a*	7} 2} –11D	*w*	9548.75	3	
			9550.05	2R	*A, S*
9484.04	00		9550.42	1	
9485.17	00		9551.02	1	
9486.10	2		9553.48*a*	5–7} U	*w*
9486.95	0}		9554.51*a*	3–5}	*w*
9487.49	1}		9556.11	2	*S*
9489.86	1		9557.33*a*	4–6	*w?*
9491.61	1		9558.49	3	
9493.41*a*	4–6} U	*w*	9558.89	3	
9494.49*a*	6–8}	*w*	9559.70*a*	000	*S*
9496.54	0B}		9562.70	4	
9497.51*a*	5–7}	*w*	9563.91	3	
9498.88	00		9565.11	3	
9499.60*a*	3–5	*w*	9566.16*a*	4–7	*w*

TABLE I—*Continued*

λ	Intensity	Source Element	λ	Intensity	Source Element
9568.91*a*	3–5	*w*	9640.26	1}	*S?*
9570.42	1B		9640.68	2}	
9571.38*a*	3–5	*w*	9643.17	1	*S?*
9572.85	1		9645.06*a*	2}8D	*w*
9574.42	0		9645.59*a*	2}	*w*
9575.75	1		9646.50	2	
9577.10	2		9648.68*a*	1–3	*w?*
9579.36*a*	0–2	*w?*	9649.53	0V	
9580.05*a*	3–5	*w?*	9650.28	00	*S*, Fe?
9581.12*a*	3–5}U	*w*	9651.02*a*	00}	
9581.84*a*	2–4}	*w*	9651.33*a*	00}	
9583.66	0		9651.97	1	
9584.82	0		9652.90	2	*A, S*
9585.92	2D		9653.64	000	
9587.17	3		9654.68	2	*S, A*, Fe?
9588.57	4}		9656.17	1V	
9589.32	5}		9657.37	2	
9590.28	4		9658.47	0	*S?*
9592.00	2}		9659.78	2	
9592.62	3}		9660.92	3	
9594.20	2		9662.36	3V	
9594.86	2		9663.26	0	
9596.46	1B		9664.04	00	
9597.84	4D		9664.68	3R	
9598.91	2		9666.59	1}	
9599.60	0		9667.21	2}	
9600.55	0		9668.27	0	
9601.22	2		9670.04	2V	
9603.43	1V		9670.67	3V	
9604.62	2}	*S?*	9680.41	4	
9605.24	2}		9681.10	0	
9606.22	2		9681.82	1	*S?*
9608.11	4B		9682.70	00	
9610.11	2		9684.25	0B	
9610.69	00		9685.81	00	
9614.13	1		9686.44	2	
9615.26	5D		9688.72	0	
9618.14	3R		9690.21	00	
9620.08	2		9691.93	3	
9621.28	3	*A, S?*	9693.99	00	
9622.74	3		9694.74	0B	
9624.56	2		9698.32	2	
9625.32	0}		9699.68	00}	
9625.83	0}		9700.15	0}	*S?*
9626.40	2	*A, S?*	9701.47	3	
9628.20	1		9705.53	00B	
9628.74	1		9708.97	1	
9629.32	000		9715.33	4	
9630.06	00		9723.18	2	
9633.58	00		9724.62	2	
9636.16*a*	4–9	*w*	9730.66	1	
9637.58*a*	4–7	*w?*	9735.07	3BV	
9638.45	1	*S*	9736.63	5BDR	

TABLE I—*Continued*

λ	Intensity	Source Element	λ	Intensity	Source Element
9737.83*a*........	0	....	9782.35........	2	....
9738.54*a*........	0	....	9787.19*a*.......	0	....
9743.53.........	3B	....	9791.09........	2	....
9749.36.........	3	....	9793.38*a*.......	1B	....
9753.90.........	2	....	9795.26*a*.......	00	....
9757.74.........	2	....	9799.52........	2	....
9761.73*a*........	00	....	9801.78........	2	....
9762.90.........	2BR	....	9803.27........	1	....
9764.14*a*........	00B	....	9813.48*a*.......	0	....
9765.51.........	2B	....	9817.70*a*.......	00	....
9768.71*a*........	0B	....	9825.57*a*.......	00	....
9774.00.........	2B	....	9831.97*a*.......	0	....
9776.84.........	1	....	9848.89*a*.......	0	....
9779.46.........	2	....			

The separation of the solar and telluric lines is based chiefly upon two rotation plates. As the Doppler displacement due to solar rotation is of the order of 0.13 A, there is little doubt as to the origin of well-defined lines. But if the lines are diffuse, unsymmetrical, or blended, question arises. If noticeable displacement occurs on one plate but not on the other, a question mark has been placed after the *S*, which is used to indicate lines of solar origin. If the evidence of blending is unmistakable it has been indicated by *A*, *S*. Lines due to water-vapor have been indicated by *w*, and lines showing decided asymmetry by V or R placed after the intensity, according as the line is shaded to the violet or the red, respectively. Where lines were not completely resolved, it has been indicated by joining the intensities by brackets. Where they were practically unresolved, U has been placed after the bracket. Broad lines have been indicated by B.

In conclusion it may be stated that the monochrometer, used instead of a screen, has certain unquestionable advantages over any of the screens at present available: (1) it removes all scattered light from the background and makes it possible, by increasing the exposure sufficiently, to obtain the very faint lines, which are especially important in the region under investigation; (2) it is faster than the battery of screens found necessary to remove even the major portion of the extraneous light in the region beyond

9400 A; (3) it presents for any limited portion of the region a very convenient method of grading the exposure to suit the sensitiveness of the plate.

The results of the investigation show (1) that at least one-fifth of the lines of 0 intensity or less are of solar origin; (2) that one-third of these solar lines are due to iron; (3) that a very strong water-vapor band exists between 9300 A and 9650 A.

The fact that in the present case, as well as in the recent work by Burns and also in the early investigations of Abney, it was found impossible to photograph beyond 9900 A is probably to be explained by the presence of the strong absorption band at about 1 μ, which was designated by Langley[1] by the symbol ϕ. The rapidly falling sensitiveness of the plates renders it impossible to photograph any portion of the spectrum beyond this band.

I am indebted to Mrs. Brackett for the computation and reduction of the measures, and to Dr. St. John and Mr. Babcock for furnishing me with wave-lengths in both sun and iron arc based on the International system. It gives me great pleasure to express my appreciation to these and also to other members of the staff for their interest and help.

MOUNT WILSON OBSERVATORY
September 1920

[1] *Annals Smithsonian Astrophysical Observatory*, 1, 1900.

THE VARIATION WITH TEMPERATURE OF THE ELECTRIC FURNACE SPECTRUM OF MANGANESE[1]

By ARTHUR S. KING

ABSTRACT

Variation of the electric furnace spectrum of manganese with temperature to 2400°.—The spectrum produced in the tube-resistance furnace at 1700°, 2000°, and 2400° C. was examined from λ 2795 to λ 8200; but no lines were found beyond λ 6500. Table I contains the relative intensities of the lines in the arc spectrum and in the furnace spectra for the three temperatures; it also gives the *temperature classification* of these lines according to the method used in previous articles. Some lines observed at 1560° C. are given in Table II; the triplet λ 4031 to λ 4035 was still strong and well reversed at this low temperature. As with other furnace spectra, the ultra-violet wave-length limit is shorter the higher the temperature. In the discussion the interesting behavior of some of the lines is pointed out. None of the enhanced lines given by Lockyer occur in the furnace spectrum.

The following results for the furnace spectrum of manganese were obtained by the methods used in previous studies of metallic spectra.[2] Manganese metal was used in the tube furnace, the inclosing chamber being pumped to a pressure of a few millimeters. Temperatures of approximately 1700°, 2000°, and 2400° C., designated as "low," "medium," and "high," respectively, were employed in studying the range of spectrum from λ 2800 to λ 6600. The peculiarities of the spectral lines as regards the temperature at which they first appear and the rate of increase with rising temperature have been tabulated from these data.

The spectrograms were made for the most part with the first and second orders of a fifteen-foot concave grating, while the very bright spectra given by the second order of a one-meter grating were used for a few photographs.

The operation of the furnace, when the tube was charged with manganese, was without notable features other than the lack of

[1] *Contributions from the Mount Wilson Observatory*, No. 198.

[2] *Mt. Wilson Contr.*, Nos. 66, 76, 94, 108, 150, 181; *Astrophysical Journal*, **37**, 239, 1913; **39**, 139, 1914; **41**, 86, 1915; **42**, 344, 1915; **48**, 13, 1918; **51**, 179, 1920.

carbide formation, in which this metal contrasted strongly with iron. Instead of sticking to the tube and gradually eating through, the manganese vaporized and then, in diffusing from the tube, condensed in the cooler portions at the ends, leaving but little residue in the hotter region. This necessitated frequent renewal of the charge of metal during the run.

In order to hold the temperature unchanged during the rather long exposures at low and medium temperatures, direct current from a large generator was frequently used on account of the close adjustment of voltage which can be made. As in the case of the iron spectrum,[1] no difference was observed between the effect of direct and alternating currents at a given temperature.

EXPLANATION OF TABLE I

The first column of Table I gives the arc wave-lengths measured by Exner and Haschek,[2] except in a few cases for which the wave-lengths of close doublets, on the international system, were taken from the measures of Kilby.[3] Frequent references to notes at the end of the table are indicated by asterisks, while a dagger means that the line was found by Kilby to be decidedly stronger in the spark than in the arc.

As in previous papers, the remaining columns give the intensity estimates for lines in the arc and for three furnace temperatures. Nebulous lines are indicated by "n" after the value of the intensity, while "r" and "R" indicate partial and complete self-reversal. Lines of Class I and Class II are strong at low temperature, those of Class II strengthening more rapidly as the temperature rises. Lines of Class III are absent or faint at low temperature, but appear at medium temperature, and are usually considerably stronger at high temperature. Class IV appears at the highest furnace temperatures, while Class V is usually absent in the furnace. "A" after the class number indicates that the line in question is relatively weak in the arc—usually not more than half as strong as in the high-temperature furnace.

[1] *Mt. Wilson Contr.*, No. 193; *Astrophysical Journal*, **52**, 187, 1920.

[2] *Spektren der Elemente bei normalem Druck*, Leipzig, 1911.

[3] *Astrophysical Journal*, **30**, 243, 1909.

TABLE I

TEMPERATURE CLASSIFICATION OF MANGANESE LINES

λ (Exner and Haschek)	Arc Intensity	Furnace Intensities			Class
		High Temperature	Medium Temperature	Low Temperature	
2794.92	500R	500R	...	...	IV
2797.05	5	1	...	...	IV
2798.37	400R	400R	...	...	IV
2799.99	10	2	...	...	IV
2801.20	400R	400R	...	...	IV
2804.24	7	3	...	...	IV
2806.25	6	2	...	...	IV
2808.12	5	2	...	...	IV
2809.20	7	2	...	...	IV
2812.99	7	2	...	...	IV
2813.60	7	2	...	...	IV
2814.09	4	...	...	...	V
2818.09	8	3	...	...	IV
2818.85	6	1	...	...	IV
2821.58	5	2	...	...	IV
2822.68	6	2	...	...	IV
2823.40	2	1	...	...	IV
2824.5	8n	...	...	...	V
2826.8	15n	...	...	...	V
2830.92	6	2	...	...	IV
2836.43	3	1	...	...	IV
2858.85	6	1	...	...	IV
2872.68	5	1	...	...	IV
2892.77†	5	...	...	...	V
2907.32	7	...	...	...	V
2914.71	50	15	1	...	IV
2925.67*	70	{8, 10}	1	...	IV
2928.79	7	...	...	...	V
2930.35	5	2	...	...	IV
2933.19†	25	tr	...	...	V
2934.13	6	...	...	...	V
2938.00	8n	...	...	...	V
2939.40†	30	tr	...	...	V
2940.01	5	...	...	...	V
2940.330*	10	8	1	...	IV
2940.512*	10n	5		...	IV
2941.15	7	1	...	...	IV
2949.31†	30	2	...	...	IV
3007.80	6	1	...	...	IV
3008.35	4	...	...	...	V
3011.30	5	tr	...	...	IV
3011.52	7	1	...	...	IV
3014.82	5	...	...	...	V
3016.60	8	1	...	...	IV
3022.90	10	2	...	...	IV
3040.76	12	4	...	...	IV
3041.35	4	...	...	...	V
3042.87	4	...	...	...	V
3043.46	9	3	...	...	IV

TABLE I—*Continued*

λ (Exner and Haschek)	Arc Intensity	Furnace Intensities High Temperature	Medium Temperature	Low Temperature	Class
3044.69......	50	7	4	....	III
3045.70......	12	4	....	....	IV
3045.90......	5	....	....	....	V
3047.14......	15	5	1	....	IV
3048.95......	5	1	....	....	IV
3054.53......	40	8	5	....	III
3062.30......	20	5	2	....	III
3066.19......	20	5	2	....	III
3070.46......	20	6	3	....	III
3073.33......	20	7	2	....	III
3079.80......	15	6	1	....	IV
3081.52......	10	5	....	....	IV
3097.18*.....	8	1	....	....	IV
3100.43......	5	2	....	....	IV
3101.67*.....	5	4?	3?	....	III?
3110.86......	6	1	....	....	IV
3115.60......	6	....	....	....	V
3120.54......	4	....	....	....	V
3142.80......	4	....	....	....	V
3148.36......	15	5	1	....	IV
3161.19......	15	6	1	....	IV
3178.61......	15	7	1	....	IV
3207.00......	5	3	....	....	IV
3212.98......	15	9	5	1	III
3217.04*.....	8	?	?	2	II
3224.90*.....	10	?	?	2	II
3226.15......	6	5	1	....	IV
3228.20......	30	20	12	6	II
3230.81......	12	10	7	2	III
3234.0.......	15n	2	....	....	IV
3235.1.......	{10n	2	....	....	IV
	15n	3	....	....	IV
3236.90......	20	15	10	5	II
3237.4.......	20n	5	....	....	IV
3240.53......	7	10	2	....	III
3240.75......	5	6	1	....	IV
3243.93......	12	12	6	1	III
3248.64......	15	15	8	3	III
3251.27......	5	6	1	....	IV
3253.09......	12	12	7	2	III
3254.14......	5	4	....	....	IV
3256.25......	12	12	7	2	III
3258.52......	10	12	5	1	III
3260.40......	10	12	3	1	III
3264.83......	10	15	5	1	III
3267.90......	4	....	....	....	V
3268.83......	3	....	....	....	V
3270.49......	3	....	....	....	V
3273.15......	3	....	....	....	V
3278.65......	5	6	....	....	IV
3280.90......	5	6	....	....	IV
3296.16......	4	2	....	....	IV

TABLE I—*Continued*

λ (Exner and Haschek)	Arc Intensity	Furnace Intensities			Class
		High Temperature	Medium Temperature	Low Temperature	
3297.01	6	8	1	....	IV
3298.35	5	2	....	....	IV
3303.40	3	....	....	....	V
3312.05	6	3	....	....	IV
3313.41	5n	2	....	....	IV
3313.70	{4	1	....	....	IV
	{4	1	....	....	IV
3314.59	6n	3	....	....	IV
3315.07	6n	3	....	....	IV
3316.47	4	2	....	....	IV
3316.61	5n	1	....	....	IV
3317.47	10n	5	....	....	IV
3320.82	6	5	....	....	IV
3330.80	8	8	1	....	IV
3343.85	4	2	....	....	IV
3345.47	4	2	....	....	IV
3420.95	4	....	....	....	V
3439.13	6	....	....	....	V
3442.13†	30	....	....	....	V
3460.45†	25	....	....	....	V
3474.20†	12	....	....	....	V
3474.27†	10	....	....	....	V
3483.22†	20	....	....	....	V
3488.80†	20	....	....	....	V
3495.99†	10	....	....	....	V
3496.96	6	....	....	....	V
3497.66†	8	....	....	....	V
3531.94†	30	10	6	1	III
3532.14†*	50	15	10	3	III
3532.27†*	50	15	10	3	III
3547.91†	50	20	12	4	III
3548.18†	40	20	12	3	III
3548.33†	30	10	6	2	III
3569.61†	60	30	15	6	III
3569.95†	40	20	10	2	III
3570.17†	20	8	3	....	III
3577.99*	40	?	15	8	II
3586.69*	30	?	7	3	II
3595.29	20	12	4	1	III
3607.69	20	10	10	4	II
3608.66	20	10	10	4	II
3610.49	20	10	8	2	III
3619.42	15	10	8	1	III
3623.96	15	8	6	1	III
3629.89	12	5	4	tr	III
3660.58	5	....	....	....	V
3670.00	4	2	1	....	III
3670.67	5	3	2	....	III
3677.13	4	....	....	....	V
3682.23	4	....	....	....	V
3693.83	6	....	....	....	V
3696.70*	8	....	....	....	V

TABLE I—*Continued*

λ (Exner and Haschek)	Arc Intensity	Furnace Intensities			Class
		High Temperature	Medium Temperature	Low Temperature	
3701.88*.....	4	?	2	....	III
3706.23......	5	....	....	....	V
3719.06......	5	....	....	....	V
3732.05......	5	....	....	....	V
3790.38......	10	8	8	2	III
3799.40*.....	4	?	2	....	III
3800.70......	4	....	....	....	V
3802.05......	4	....	....	....	V
3806.90......	20r	15	15	15	I
3809.75*.....	10	?	10	5	II
3816.90......	5	3	3	1	III
3823.64......	20r	15	15	10	II
3824.03*.....	10	?	10	4	II
3829.80*.....	5	?	4	1	III
3834.01*.....	8	?	8	5	II
3834.50......	12	12	12	8	II
3839.90*.....	8	?	6	3	II
3841.23......	10	8	8	4	II
3844.12*.....	7	?	6	3	II
3918.46......	3	....	....	....	V
3921.94*.....	3n	?	tr	....	IV
3924.23*.....	3	?	tr	....	IV
3926.63......	10	....	....	....	V
3929.41......	2	2	....	....	IV
3953.00......	3	....	....	....	V
3985.40......	3	....	....	....	V
3986.98......	3	....	....	....	V
4018.28......	20	20	20	15	I
4026.58......	4	....	....	....	V
4030.92......	200R	200R	200R	200R	I
4033.21......	150R	150R	150R	150R	I
4034.62......	100R	100R	100R	100R	I
4035.88......	15	15	15	12	I
4041.53......	50r	35	30	25	I
4045.31*.....	4	....	....	....	V
4048.90......	15	15	12	10	I
4055.70......	20	20	18	15	I
4058.10......	4	....	....	....	V
4059.09......	10	12	10	8	I
4059.54*.....	5	?	tr	....	IV
4061.90......	5	....	....	....	V
4063.70*.....	8	8?	8?	6?	I
4070.48......	5	6	5	3	II
4079.38......	12	15	12	10	I
4079.61......	10	12	10	8	I
4083.11......	12	15	15	12	I
4083.82......	12	15	15	12	I
4235.125*....	6	2	2	1	II
4235.306*....	8	6	6	4	I
4239.90......	5	2	2	1	II
4257.83......	5	2	2	1	II
4266.10......	6	2	2	1	II

TABLE I—*Continued*

λ (Exner and Haschek)	Arc Intensity	Furnace Intensities			Class
		High Temperature	Medium Temperature	Low Temperature	
4281.30	6	3	3	2	II
4312.71*	3	?	1	tr	II
4412.04	3	1	....	....	IV
4415.04	10	6	5	3	II
4436.52	8	6	4	1	III
4451.78	15	12	10	6	II
4453.19	6	5	3	1	III
4455.20	5	4	2	tr	III
4455.51*	6	?	3?	1?	III?
4456.02	6	5	2	tr	III
4457.22	5	3	1	tr	III
4457.76*	8	?	?	?	?
4458.48	12	8	4	2	II
4460.59*	3	?	?	?	?
4461.30	8	4	2	tr	III
4462.20	20	12	6	2	III
4464.88	8	8	5	3	II
4470.33	6	6	4	1	III
4472.98	5	5	3	1	III
4490.27	5	6	4	1	III
4499.09	7	8	6	2	III
4502.40	7	8	6	2	III
4605.52	4	....	....	....	V
4626.69	4	3	2	....	III
4671.89	3	....	....	....	V
4701.31	3	....	....	....	V
4709.89	10	6	4	1	III
4727.70*	10	?	4	1	III
4739.30	8	6	3	1	III
4754.24	50	50	60	40	I
4761.73	10	10	6	1	III
4762.60	30	25	20	5	III
4766.08	10	10	8	2	III
4766.63	20	20	15	4	III
4783.62	50	50	60	40	I
4823.71	50	50	60	40	I
4966.03	3	3	2	....	III
5005.03	2	2	1	....	III
5017.77	2	....	....	....	V
5074.92	2	....	....	....	V
5118.10	3	....	....	....	V
5151.10	3	....	....	....	V
5196.76	3	3	2	....	III
5197.40	1	1	....	....	IV
5255.48	4	4	3	....	III
5341.25*	20	50	25	4	IIIA
5377.86	6	1	tr	....	III
5394.89	10	30r	30	30	IA
5399.70	4	2	1	....	III
5407.67	5	10	8	2	IIIA
5413.90	2	1	....	....	IV
5420.61	10	20	15	3	IIIA

TABLE I—*Continued*

λ (Exner and Haschek)	Arc Intensity	Furnace Intensities			Class
		High Temperature	Medium Temperature	Low Temperature	
5432.75	4	35	35	35	IA
5457.64	1	2	2	1	IIA
5470.88	8	20	10	4	IIA
5481.61	4	10	5	2	IIA
5506.10*	2	?	3	1	III
5517.00	7	20	10	2	IIIA
5537.99*	5	?	5	1	III
6013.74	30	30	6	1	III
6016.90	40	40	10	2	III
6022.05	50	50	12	3	III
6384.88	4	....	....	....	V
6413.77	2	4	2	....	IIIA
6441.14	8	2	....	....	IV
6491.92	15	3	....	....	IV
6605.7	6n	....	....	....	V

λ	Remarks
2926	Close doublet, just resolved.
2940.3, 2940.5	Doublet measured by Kilby. Exner and Haschek give λ2940.50.
3097	Double. Arc components about equal.
3102	Furnace line may be partly Ni.
3217, 3225	Pure absorption lines at high temperature. Partial absorption at medium temperature.
3532.14, 3532.27	λ's by Hasselberg. Exner and Haschek give λ3532.20.
3578–3587	Disturbed by carbon.
3697	Close doublet.
3702	Concealed by continuous ground at high temperature.
3799–3844	Disturbed by carbon.
3922, 3924	Concealed by continuous ground at high temperature.
4045	Close doublet.
4060	Disturbed by carbon.
4064	Blend Fe. Probable intensity of Fe line subtracted.
4235	Doublet measured by Kilby. Exner and Haschek give 4235.41.
4313	Disturbed by carbon.
4455–4457–4460	Blend with impurity lines.
4728	Disturbed by carbon.
5341	Probably double.
5506, 5538	Disturbed by carbon.

DISCUSSION OF RESULTS

Several groups of lines whose behavior is of special interest may be noted. The first is the strong triplet at λλ 2795, 2798, 2801. These lines reverse widely in the high-temperature furnace. The emission wings fill up the space between the lines, but are of low density. The effect is that of three absorption lines on a weak

continuous ground. No temperature stage has been found which gives these as narrow emission lines. Presumably they will occur as such at high temperature when a trace of manganese is present, though an examination of some iron spectrograms failed to show them. At reduced temperature the lines are not narrow or indeed visible at all, because the furnace spectrum does not then extend so far into the ultra-violet. This is a peculiarity often met with in furnace spectra; lines in the ultra-violet having the characteristics of low-temperature lines require high temperatures for their production because the low-temperature spectrum ceases before this wave-length is reached. The effect is so general with different elements that there seems to be no reason to ascribe it to absorption by a vapor within the furnace.

At about λ 3000, the medium temperature begins to show some lines distinctly. The prominent lines up to this point, in addition to the λ 2800 triplet, are those of the series triplet $\lambda\lambda$ 2915, 2926, 2941, of which the last two are clearly complex and probably also the first. The components of λ 2926 are resolved in the furnace spectrum. This triplet is given by Kayser and Runge[1] as belonging to the same series as $\lambda\lambda$ 3532, 3548, 3570, lines which are also complex; but the two triplets appear in different temperature classes because the member of shorter wave-length occurs at the extreme limit of the medium-temperature spectrum.

$\lambda\lambda$ 3217 and 3225 show a peculiar behavior. At high temperature they are simple absorption lines, with no sign of emission wings. Their strength at medium temperature is uncertain, the emission being partly neutralized by absorption, while at low temperature they are sharp emission lines. No other lines of this type occur in the spectrum.

The tendency, which prevails throughout the spectrum, for lines of similar type to appear in groups is illustrated by those from λ 3442 to λ 3498. They are absent in the furnace but strong in the arc, and yet stronger in the spark. They are thus enhanced lines of intermediate type. None of the enhanced lines given by Lockyer[2] occur in the furnace spectrum.

[1] *Abhandlungen der preussischen Akademie*, 1904.

[2] Solar Physics Committee, *Tables of Wave-Lengths of Enhanced Lines*, 1906.

The series triplet λ 3532 to λ 3570, each member of which has three components, is also strengthened in the spark. In the furnace these lines appear between 1600° and 1700°, but strengthen very rapidly with increasing temperature.

The prominent low-temperature group between λλ 4000 and 4100 contains the very sensitive triplet λλ 4031, 4033, 4035. These lines are of extreme persistence, occurring very generally as impurity lines in arc spectra. Their intensity in the furnace seems to depend very largely on the vapor density, and with an ordinary charge of manganese present they are always widely reversed. This was the condition at the lowest temperature used, 1560°, when most of the low-temperature lines were barely registered on the plate. The intensities of this triplet given in the table therefore signify little relatively to the general run of the manganese lines. At low temperature, with much vapor present, they can be made much stronger than at high temperature with less vapor. The extreme sensitiveness of these three lines to anomalous dispersion, the degree of which is found to depend on the tendency of a line to reverse, was noted in a former paper.[1]

The group in the blue near λ 4450 consists of strong arc lines which are relatively weak in the furnace, being for the most part in Class III. Near λ 4800 several prominent furnace lines occur, among them the triplet of Class I, λλ 4754, 4784, 4824. These are very strong at low temperature and are placed by Kayser and Runge in the first sub-series, another member of which is the triplet at λλ 3148, 3161, 3179. The latter lines are beyond the range of the low-temperature furnace, appearing faintly at medium temperature.

Near λ 5400 is another set of prominent lines, which in general are relatively stronger in the furnace than in the arc, a class not noted in other parts of the manganese spectrum. λλ 5395 and 5433 are remarkable for their strength at low temperature. λ 5341 is stronger than either of these at high temperature, but falls off rapidly below 2000°. The temperature of the furnace, especially in the lower range, may be closely gauged by the relative intensity of λ 5341 as compared with λ 5395 or λ 5433.

[1] *Mt. Wilson Contr.*, No. 130; *Astrophysical Journal*, **45**, 254, 1917.

The red end of the manganese furnace spectrum is weak, except for the triplet at λ6014 to λ6022 and this fades rapidly with decreasing temperature. The spectrum was photographed with dicyanin-bathed plates as far as λ8200, but no lines were found in the furnace beyond λ6500.

Table II lists what may be regarded as the residual furnace lines. The intensity estimates were made from a spectrogram of

TABLE II

Manganese Lines in Furnace at 1560° C.

λ	Intensity	λ	Intensity
3806.90	2	4055.70	5
3823.64	1	4059.09	1
3834.50	1	4063.70	1
4018.28	3	4079.38	3
4030.92	100R	4079.61	
4033.21	75R	4083.11	2
4034.62	50R	4083.82	2
4035.88	3	4754.24	10
4041.53	10	4783.62	10
4048.90	3	4823.71	10

long exposure taken with the one-meter concave grating. The temperature of the furnace read 1560° C. The lines of the triplet λ4031 to λ4035 are strong and well reversed. Evidently they are emitted at a considerably lower temperature than that used here. The other lines in Table II are the most pronounced low-temperature lines and in some cases are just strong enough to be distinctly registered. λλ 5394.89 and 5432.75 would doubtless be listed among these lines if the photograph had included the region.

Mount Wilson Observatory
November 1920

THE ORBIT OF THE SHORT-PERIOD SPECTROSCOPIC BINARY 65 τ CYGNI

By J. S. PARASKÉVOPOULOS[1]

ABSTRACT

Spectroscopic binary components of the triple system 65 τ Cygni.—This interesting system is a visual binary whose brighter component is a spectroscopic binary. During 1920 several continuous series of spectrograms obtained with the Bruce spectrograph of the Yerkes Observatory enabled the *elements of the orbit* to be computed. The period is only $3^h25^m.4$, the shortest yet known, and $a \sin i$ is only 14,924 km. Taking the parallax of the system as $0''.031$, the distance apart of the components comes out about 1,600,000 km. But from the brightness of the brighter component, absolute magnitude about 1.5, its diameter is probably about 9,000,000 km. Apparently, then, the separation of the components is less than the diameter of one of them. But neither the hypothesis of a pear-shaped body nor that of a pulsating star seems to explain the facts satisfactorily.

The star 65 τ Cygni ($\alpha = 21^h10^m.8$, $\delta = +37°37'$) is a triple system of great interest. Alvan G. Clark found in 1878 that this $3^M.8$ star has a companion of about 8^M. It was soon recognized that these form a visual binary system.[2] The latest elements which fairly represent the recent measures are those of Aitken:[3]

$P = 47$ years	$\omega = 105°.5$
$T = 1889.60$	$\iota = \pm 42°.7$
$e = 0.22$	$\Omega = 149°.8$
$a = 0''.91$	Angles decreasing

Professor Storrs B. Barrett,[4] of the Yerkes Observatory, detected some years ago that the spectrum of this star shows a variable radial velocity.

Spectrum.—The limiting distance for the Bruce spectrograph of the Yerkes Observatory being in practice between $2''$ and $3''$, the spectrum of the two components of the visual system cannot be studied separately. The spectrograms obtained record only a single spectrum, belonging to the brighter component: they do not show the spectrum of the fainter visual component or of the spec-

[1] Of the National Observatory at Athens. Volunteer Research Assistant at Yerkes Observatory, 1919–1921.

[2] Burnham, *General Catalogue of Double Stars.*

[3] *Publications of the Lick Observatory*, **12**, 161.

[4] *Astronomische Nachrichten*, **177**, 174, 1908.

troscopic companion. The spectrum of this bright component is of type F0, according to the *Revised Harvard Photometry*.[1]

Since the discovery of the binary character of τ Cygni, a large number of spectrograms of this star have been taken at the Yerkes Observatory with the Bruce spectrograph arranged for one prism. The time usually required for a satisfactory exposure is between 25 and 40 minutes. A comparison spectrum of titanium and of iron was impressed on all the plates. All the spectrograms were measured on the Gaertner measuring machine and reduced by the author. The following are the wave-lengths for the lines that have been used chiefly:

Fe 4045.975	Hδ 4101.900	Fe 4260.640	Hγ 4340.634	Ti 4443.976
Fe 4063.759	Sr 4215.703	Cr 4289.885	Cr 4351.930	Mg 4481.400
Fe 4071.908	Ca 4226.904	Fe 4299.410	Ti 4395.203	Ti–Co 4549.808
Sr 4077.885	Fe 4250.945	Fe 4325.939	Fe 4404.927	Ti 4563.939
				Ti 4572.156

TABLE I

(For Julian Day 2, 422,522)

Plate	Date (G.M.T.)	Exposure	V	n	V_c	O−C
		m	km		km	km
I B 5859...	1920 July 16 .597	40	−23.98	17	−26.76	+2.78
5860...	.630	40	−29.95	19	−29.12	−0.83
5861...	.659	36	−15.88	14	−14.74	−1.14
5862...	.686	33	−16.54	17	−16.50	−0.04
5863...	.713	33	−22.99	16	−21.47	−1.52
5864...	.740	32	−22.67	17	−26.90	+4.23
5865...	.766	32	−29.38	18	−30.24	+0.86
5866...	.790	25	−20.37	14	−18.96	−1.41
5867...	.819	24	−14.66	14	−15.10	+0.44
5868...	.850	40	−19.08	9	−20.40	+1.32
5869...	.881	28	−27.85	14	−26.60	−1.25

Period and elements of the orbit.—An examination of the radial velocities showed that the period must be short, but I failed to find any period that would fit them all until on July 16, 1920, I secured in one night a series of eleven plates from which the period was found equal to $0^{d}.1425$ (or $3^{h}25^{m}.2$). The results of the observations and measurements for this date are collected in Table I. Mr. Frank R. Sullivan, engineer in charge of the 40-inch telescope, assisted me in securing the plates. Under n are given the number

[1] *Harvard Annals*, **50**, 181.

of lines measured for each plate. V_c is the computed radial velocity and O−C the difference between the observed and the computed radial velocity. With the foregoing data and the Lehmann-Filhés

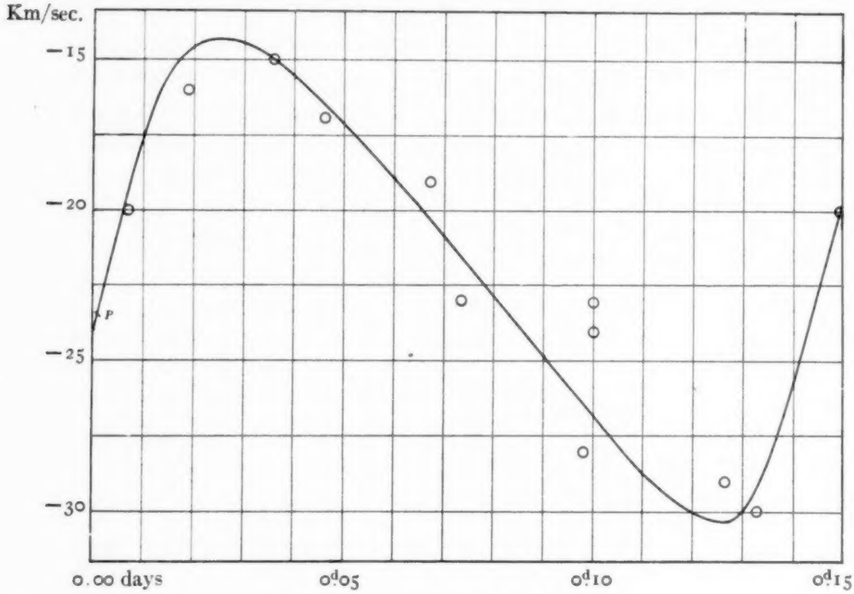


FIG. 1.—Velocity-curve of 65 τ Cygni

method, I obtained the following elements for the orbit of the spectroscopic binary,

$P = 0^d.1425$ $\qquad T = \text{J.D. } 2{,}422{,}522.641$

$\omega = 263°.0$ $\qquad a \sin i = 14{,}924$ km

$e = 0.306$ $\qquad K = 8.0$ km/sec.

$\mu = (7 \times 360°) + 6°.333$ $\qquad \gamma = -22.0$ km/sec.

Owing to the possibility of rapid changes in the amplitude and shape of the velocity-curve, similar to those found by Mr. R. K. Young[1] in the case of 12 Lacertae, I did not try to reduce to one period all the obervations obtained during this year. Nevertheless, I attempted to improve the period above, deduced from a single night's observations, by using short series of plates taken on March 29, April 5, 6, and June 18 of this year. A period of 0.14265 day seems to represent all these observations in a satisfac-

[1] *Publications of the Dominion Astrophysical Observatory*, Victoria, 1, No. 2.

tory way. This value of P corresponding to $3^h25^m.4$ is the shortest period thus far found for any spectroscopic binary.

The value of a sin i.—The value of $a \sin i$ for τ Cygni is extremely small, almost equal to the earth's diameter. This is also the case for all the spectroscopic binaries of very short period, like β Cephei, 12 Lacertae, β Canis Majoris, etc. The value of the semi-major axis a itself remains unknown as long as the inclination is not determined. But since the average value of $\sin i$ cannot be very small, this is an indication that a is also small.

The combined magnitude of the spectroscopic binary is $3^M.82$. As no lines of the spectroscopic companion are recorded, we infer that its magnitude cannot be more than 5.5. Consequently the magnitude of the bright component cannot be less than 4.0. Accepting this lowest limit, I found that the absolute magnitude of this bright component is 1.5 (by using the formula $M=m+5+5\log\pi$ and adopting a parallax of $0''.031$ given by Adams).[1] As the absolute magnitude of the sun is 5.5, it follows that the difference in brightness between those two stars is $2.5^{4.0}=39.81$. If now we suppose that equal surfaces of the sun and of the bright component of the spectroscopic binary emit the same quantity of light,[2] we deduce that the surface of the latter is forty times the surface of the sun, and consequently the diameter of the star is about 6.3 times the diameter of the sun, i.e., equal to $6.3\times1,400,000=8,820,000$ km.

Let us now call

M = the mass of the bright component
m_1 = the mass of the spectroscopic companion
m_2 = the mass of the visual companion
x = distance between the bright component and its spectroscopic companion

Supposing the semi-major axis of the visual orbit to be 1 we get, the period being 47 years:

$$\left(\frac{47}{0.00039}\right)^2\cdot\frac{M+m_1+m_2}{M+m_1}=\frac{1}{x^3}.$$

[1] The values of the trigonometric parallax of τ Cygni present large discrepancies. I adopted the value of $0''.031$ given by Adams and Joy in *Contributions from the Mount Wilson Observatory*, No. 142.

[2] The spectral type of 65 τ Cygni being F0.

G. Van Biesbroeck[1] obtained as a value of the mass-ratio in the visual binary:

$$\frac{M+m_1}{M+m_1+m_2}=0.53.$$

Consequently,

$$x^3=0.53\,(0.00039/47)^2 \text{ and } x=0.000418.$$

If we adopt $\pi=0''.031$ as we did before, and $0''.91$ as the value of the semi-major axis of the visual orbit, we find

$x=0.000418\times 0.91\times 149{,}000{,}000/0.031=1{,}830{,}000$ km, or 0.0123 astronomical units, and for the mass of the spectroscopic system:

$$M+m_1=\frac{x^3}{P^2}=\frac{(0.0123)^3}{(0.00039)^2}=12.2 \text{ times the mass of the sun.}$$

All these values seem very reasonable, but we must not forget the uncertainty of the determinations of the parallax. The distance x is inversely proportional to the adopted parallax, and the total mass of the spectroscopic binary varies as the reciprocal of the cube of the parallax.

As we saw, the bright component must be larger than our sun, i.e., larger than the distance x between the former and its spectroscopic companion. In that case, we have necessarily to do with a pear-shaped body. But how could we explain the periodic shifting of the spectral lines of a pear-shaped body? Such a body would evidently give diffuse lines, but without variable displacements. In order to reconcile these conflicting conclusions, attempt was made to study the problem on the assumption of a single pulsating body. Unfortunately the deficiency of sufficient data does not enable us to get any positive result. By means of Lord Kelvin's[2] formula

$$T_n=2\pi\sqrt{\frac{2n+1}{2n(n-1)}}\cdot\sqrt{\frac{a}{g}},$$

where T_n is the period of oscillation of the harmonic of order n, a is the radius of the sun, g is the surface gravity. Professor F. R.

[1] *Astronomical Journal*, **29**, 173, 1916.

[2] *Philosophical Transactions*, **153**, 612, 1863.

Moulton[1] finds for our sun a pulsation period of 3^h8^m ($0^d.13056$), whence we see that in the case of 65 τ Cygni its period of $0^d.1425$ may just as well be explained by the pulsation hypothesis. Professor Moulton, examining the effects of oscillations of the sun upon its temperature and rate of radiation, concludes that: "If the sun were undergoing a dilatational oscillation of extreme range of $0''.1$ in diameter (i.e., 70 km), the rate of radiation at minimum radius would be 2.56 times that at maximum radius. That is, the variation would be more than one star magnitude." If we suppose 65 τ Cygni to be a pulsating star, we can find a ***rough value*** of the semi-amplitude of the harmonic motion of a molecule on the surface of the star by means of the known formula of the harmonic undamped motion

$$v=2\pi A/T\cdot\cos 2\pi\cdot t/T,$$

where v is the velocity at the time t; T is the period of oscillation; A is the semi-amplitude of the oscillation. The maximun velocity of this molecule is given by the formula

$$v=2\pi A/T$$

and it is of course equal to K, half the range of the observed radial velocities ($v=K=8$ km/sec.). Consequently $2A=30{,}730$ km, as against 70 km as the upper limit for the sun, and still the star is not known to be variable.

In any case, it seems that the results concerning the short-period spectroscopic binaries begin to open a new view as to the evolution of the stellar systems.

In closing, the author wishes to express his indebtedness to Professor Edwin B. Frost, Director of the Yerkes Observatory, and to Professor G. Van Biesbroeck, for their interest and suggestions during the progress of the present work.

Yerkes Observatory
September 1920

[1] *Astrophysical Journal*, **29**, 261, 1909.

THE VACUUM-SPARK SPECTRA IN THE EXTREME ULTRA-VIOLET OF CARBON, IRON, AND NICKEL

By R. A. MILLIKAN, I. S. BOWEN, and R. A. SAWYER

ABSTRACT

Spectroscopy of the extreme ultra-violet.—(1) A *concave grating* to be suitable for work in this region must satisfy far more rigorous demands than for work in the visible and should throw most of the light into the first-order spectrum. The authors therefore had some gratings ruled with great precision and with a light touch so that about half the original surface was left between the rulings. It was not found practical to increase the number of lines to more than 1100 per mm. (2) *Measurement of the wave-lengths.* Equations for the corrections to be applied to plate measurements because of the flatness of the plate and its inclination to the axis of the grating are derived, and the use of spectrum lines of higher order to determine this angle of inclination is explained.

Vacuum-spark spectra of carbon, iron, and nickel in the extreme ultra-violet.—The intensities and wave-lengths, accurate to about 0.2 A, of about 75 lines due to carbon (λ 360–λ 1931), of about 200 lines due to iron (λ 271–λ 2153), and of about 75 lines due to nickel (λ 731–λ 1860) are given in Tables I–III.

In preceding papers[1] report has been made upon the development of a method for the extension of the study of spectra into hitherto-unexplored regions of the ultra-violet and upon some of the most important of the results which have thus far come from this study. The present paper deals: (1) with the ruling of gratings suitable for work with very short wave-lengths, (2) with the technique of the measurement of wave-lengths in this region, and (3) with a detailed tabular statement of the character of the spectra emitted by the atoms of carbon, iron, and nickel.

I. THE GRATING PROBLEM

In the ordinary process of ruling gratings for work in the visible portion of the spectrum the surface of the grating is entirely cut away by the point of the diamond and the spectrum is produced by reflections from a series of new surfaces formed by the facets of the diamond. This in general throws the major portion of the

[1] *Astrophysical Journal*, **52**, 47, 1920, and **52**, 286, 1920; *Physical Review*, **12**, 168, 1918, and *Science*, **19**, 138, 1919.

light into a spectrum of higher order than the first, an indispensable condition for the high resolution upon which the excellence of a grating ordinarily depends. For work in exploring the extreme ultra-violet, on the other hand, the overlapping of spectra renders all spectra save that of the first order well-nigh useless, so that it becomes indispensable to throw the major portion of the light into that order.

Again the ratio of grating-space to wave-length is ordinarily of the order of 4 or 5 to 1. In the case of the shortest wave-lengths which have been obtained in the present work this ratio is more than 100 to 1. This condition clearly imposes immensely greater demands upon the perfection of the reflecting surface and the exact identity of the rulings than are imposed by work in the visible region.

We therefore soon discovered that gratings which were excellent for work in the visible and of which we had high hopes for this work were altogether useless. We accordingly tried the expedient of ruling our gratings with a very "light touch" so as to leave a portion of the original surface functioning in the production of the spectra. If by such a procedure we succeed in cutting away just half of the surface, for example, the whole light will be thrown into the central image and into the odd orders in the intensity ratios 1, 0.4, 0.05, etc., the energy falling off as the inverse square of the order (always odd). The gratings with which we have succeeded in obtaining our shortest wave-lengths have been ruled as nearly as possible in this way.

On account of the necessity of leaving between the rulings a portion of the original surface no particular success has been had in increasing the number of lines to the mm. The largest number used has been 1100 per mm, and the usual number about 500.

II. THE MEASUREMENT OF WAVE-LENGTHS

Since for these short waves, incident nearly perpendicularly upon the grating, the spectra are very close to the so-called *normal* type, the first procedure in the determination of wave-length has been to find the approximate wave-length λ' of every new line by means of a grating-constant obtained by dividing the

wave-length of the standard Al lines $\lambda\lambda$ 1854.7 and 1862.7 by their measured distances from the central image. These two standard lines were in general just obtainable at one end of our photographic plates when the central image was near the other end, their distances from the central image being about 8 cm, when the focal length of the grating was 83.5 cm and the grating-constant 505 lines per mm.

To the approximate wave-length λ' thus obtained were applied corrections to take account of the facts (1) that the photographic plate was straight instead of curved, and (2) that it might be slightly inclined to the normal to the grating. These corrections were obtained as follows (see Fig. 1):

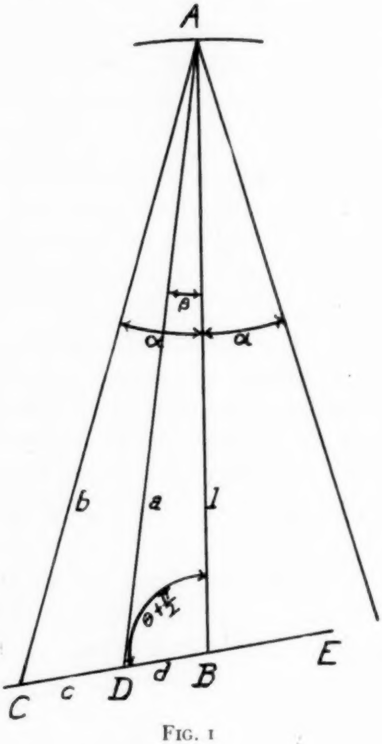


FIG. 1

Let

- A be the center of the grating
- CE the photographic plate
- AB the axis of the grating
- AC the path of a ray to the central image of the slit
- AD the path of a ray to any spectral line
- s = the grating-space
- λ = the true wave-length of any line
- λ' = the approximate wave-length of any line as given by the assumption of a normal spectrum
- λ_0 = the wave-length corresponding to a line at B on the normal to the grating

And let

$$AB=l$$
$$AD=a$$
$$AC=b$$
$$CD=c$$
$$DB=d$$

and

$$BAC=\alpha$$
$$BAD=\beta$$
$$CBA=\frac{\pi}{2}+\theta$$

Then by the simple theory of the grating

$$\frac{\lambda}{s} = \sin \alpha - \sin \beta \tag{1}$$

also since λ_0 is that wave-length for which $\sin \beta = 0$

$$\frac{\lambda_0}{s} = \sin \alpha \tag{2}$$

But

$$\sin \alpha = \frac{c+d}{b} \sin \left(\theta + \frac{\pi}{2}\right)$$

$$\sin \beta = \frac{d}{a} \sin \left(\theta + \frac{\pi}{2}\right)$$

$\therefore$ from (1)

$$\frac{\lambda}{s} = \left(\frac{c+d}{b} - \frac{d}{a}\right) \sin \left(\theta + \frac{\pi}{2}\right) \tag{3}$$

and from (2)

$$\frac{\lambda_0}{s} = \frac{c+d}{b} \sin \left(\theta + \frac{\pi}{2}\right) \tag{4}$$

Dividing (3) by (4)

$$\frac{\lambda}{\lambda_0} = \frac{a(c+d) - bd}{(c+d)a}$$

$$= \frac{ac + (a-b)d}{a(c+d)}$$

$$= \frac{c}{c+d}\left[1 + \frac{(a-b)d}{ac}\right].$$

But by the assumption of linearity of scale

$$\frac{\lambda'}{\lambda_0} = \frac{c}{c+d}$$

$$\therefore \quad \lambda = \lambda' \left[1 + \left(1 - \frac{b}{a}\right)\frac{d}{c}\right] \tag{5}$$

But

$$b = \sqrt{l^2 + (c+d)^2 + 2l(c+d) \sin \theta}$$

$$a = \sqrt{l^2 + d^2 + 2ld \sin \theta}$$

Or, expanding and dropping terms of higher orders,

$$b=l\left[1+\tfrac{1}{2}\left(\frac{c+d}{l}\right)^2+\frac{c+d}{l}\sin\theta\right]$$

$$a=l\left[1+\tfrac{1}{2}\left(\frac{d}{l}\right)^2+\frac{d}{l}\sin\theta\right].$$

Dividing

$$\frac{b}{a}=\frac{1+\frac{1}{2}\left(\frac{c+d}{l}\right)^2+\frac{c+d}{l}\sin\theta}{1+\frac{1}{2}\left(\frac{d}{l}\right)^2+\frac{d}{l}\sin\theta}.$$

Again expanding and dropping terms of higher orders,

$$\frac{b}{a}=1+\frac{(c+d)^2-d^2}{2l^2}+\frac{c}{l}\sin\theta.$$

Substituting this value for $\frac{b}{a}$ in (5)

$$\begin{aligned}\lambda&=\lambda'\left[1-\left\{\frac{(c+d)^2-d^2}{2l^2}+\frac{c}{l}\sin\theta\right\}\frac{d}{c}\right]\\&=\lambda'\left[1-\left\{\frac{c+2d}{2l^2}+\frac{\sin\theta}{l}\right\}d\right]\end{aligned}$$

which gives as the correction term

$$\lambda-\lambda'=-\lambda' d\left\{\frac{c+2d}{2l^2}+\frac{\sin\theta}{l}\right\}.$$

Obviously the last part vanishes if $\theta=0$, i.e., if AB is normal to CE. Hence, the correction for a flat plate is merely

$$-\lambda' d\left\{\frac{c+2d}{2l^2}\right\} \tag{6}$$

And for an angle θ, if present, it is

$$-\frac{\lambda' d}{l}\sin\theta \tag{7}$$

In general sin θ can, if desired, be made so small that the corrections contained in (7) need not be used at all. (See, however, below.) To obtain the corrections corresponding to (6) the point *B* was first located by taking half the distance between the slit *E* and its direct image *C*. Then with the measured values of *c* and *d* the correction curve for (6) was plotted using $\lambda-\lambda'$ as ordinates and λ' as abscissae. This curve is shown in Figure 2. A line was then drawn from the origin to the point on the curve corresponding to

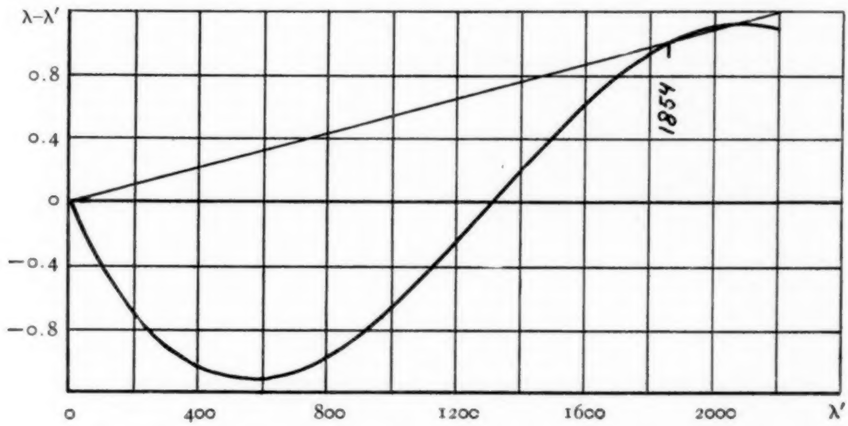


FIG. 2

the standard wave-length 1854.7. The distance between this line and the curve then represents the correction term required for any wave-length.

In practice the foregoing procedure was somewhat modified because of the appearance on the plates of second and higher orders of some of the stronger lines. With the aid of the values of λ' and the corrections obtained from Figure 2, all lines which appeared in more than one order were located with an error of not more than 0.5 A. A systematic departure from an exact multiple relationship between these measurements meant that the angle θ of equation 7 was not quite zero. To find its most probable value a curve corresponding to (7) was plotted with sin θ taken arbitrarily as 0.01. This curve is shown in Figure 3. If then the difference between a measurement on a first-order line

and one-half of the corresponding measurement on a second-order line was on the average the value found in the curve of Figure 3, the value of sin θ was considered to be 0.01. If it was

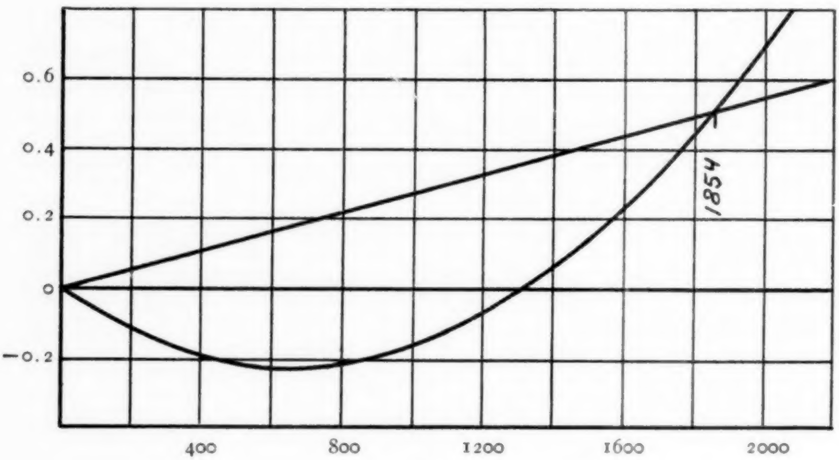


FIG. 3

twice the value found in Figure 3, sin θ was taken as 0.02, etc. The whole series of wave-lengths obtained with the aid of (6) was then corrected with the aid of (7), using the value of sin θ obtained in this way from these spectra of higher orders.

III. SPECTRA OF IRON, CARBON, AND NICKEL

TABLE I

IRON SPECTRUM

Intensity	λ	Intensity	λ	Intensity	λ
0 O?	271.5	0	663.3	0	1089.4
1	290.8	4	666.9	1	1117.9
2	294.3	4	669.9	1	1125.3
2	297.3	0	680.2	2	1143.4
0	301.0	1	691.2	1 O?	1153.4
0 O?	304.0	1	694.0	1	1158.0
2	308.5	0	696.8	0	1166.1
2	311.8	2	723.1	0	1169.2
1	330.5	3	729.9	0	1172.3
1	334.5	1	739.8	0	1179.1
0	357.6	0 O?	749.7	1	1182.5
0	361.6	2 O?	760.8	2	1186.4
5	365.8	2 C?	808.2	1	1192.2
1	377.1	2	813.7	0 C?	1194.7
4	381.1	1	816.7	1	1212.5
9 C?	385.2	1	820.1	2	1228.9
9 C?	387.7	1	823.4	0	1238.0
7	392.9	1	837.8	2	1254.1
4 O?	395.6	1	841.1	2	1260.8
3	400.8	2	845.0	1	1266.2
2	407.2	2	847.7	2	1272.2
2	411.1	2	851.8	1	1277.5
4	417.5	1	854.9	1	1285.9
3	422.0	4	859.9	0	1291.2
3	426.5	3	863.2	0 C?	1297.1
1	445.5	1	869.1	0	1301.6
3	502.4	2	873.6	0	1309.5
3	506.7	2	876.3	0	1311.1
0	519.2	2	880.6	0	1315.3
1	529.4	2	884.1	1	1317.9
1	531.7	2	891.2	1	1321.1
7 C?	548.7	0 O?	899.3	0	1345.9
7	552.1	2	911.5	0	1348.9
1	558.8	3	929.2	1	1358.1
1	562.1	0	934.8	2 C?	1362.0
3	565.7	0	937.7	1	1365.8
3	569.8	0	944.4	2	1373.9
1	577.3	1	950.2	1	1376.3
3 O?	580.2	0	955.3	2	1387.8
3	584.0	2	962.4	2	1409.4
1	588.2	1	967.0	1	1415.2
0	590.9	0	971.5	2	1430.6
3 C?	594.2	1	981.2	1	1440.7
4 O?	598.1	3	983.8	0	1449.2
4	602.4	2 Si?	994.0	0	1456.0
9 O?	609.1	2 Si?	997.8	1	1465.4
2	612.8	1	1000.3	0	1469.3
1	632.9	2	1006.0	0	1472.6
1 C?	636.9	6	1017.6	2	1525.5
0	639.6	2	1021.8	2	1532.3
1	646.4	1	1026.9	2	1538.3
1	654.5	4	1031.8	2	1542.5
2 C?	661.8	2	1062.1	0	1556.5

TABLE I—*Continued*

Intensity	λ	Intensity	λ	Intensity	λ
0	1563.6	1	1710.6	2 C?	1931.0
1	1568.6	2	1718.3	1	1937.9
0	1576.6	2	1724.0	1	1944.3
1	1580.3	0	1746.9	1	1950.6
0	1584.7	1	1770.2	2	1953.6
0	1591.7	0	1775.9	2	1959.5
1	1595.2	1	1786.1	1	1964.5
2	1597.7	1	1787.5	1	1983.1
1	1601.5	0	1792.8	1	1987.3
0	1609.3	1	1797.9	1	1992.1
0	1615.4	1 C?	1827.6	1	1995.0
1	1622.2	2	1843.9	1	2000.1
1	1626.8	1	1850.0	0	2035.7
2	1630.9	1	1860.0	0	2040.1
1	1639.9	2	1870.8	0	2051.1
0	1646.8	1	1877.6	1	2058.0
1 C?	1656.7	2	1881.9	1	2069.3
0	1658.8	1	1891.0	2	2079.8
1	1662.5	4	1895.6	1	2085.4
1	1673.3	0	1901.1	2	2091.0
1	1676.0	0	1907.0	2	2098.7
0	1681.3	0	1910.2	0	2104.4
1	1687.2	3	1914.2	0	2108.2
0	1690.7	1	1917.9	0	2145.4
1	1695.3	1	1922.6	0	2152.9
0	1702.2	2	1926.4		

TABLE II

Carbon Spectrum

Intensity	λ	Intensity	λ	Intensity	λ
0	360.5	0 O?	749.6	7	1247.5
2 Na?	372.1	1	786.5	5	1262.4
4	384.4	5	799.9	5	1278.7
4	386.4	6	806.7	2 Si?	1294.9
1	419.8	5	810.0	2	1296.8
1	450.9	0	848.4	3 Si, Ca?	1299.2
6	459.7	5	858.5	1	1310.5
1	493.7	1	884.8	2	1322.3
4	499.7	10	904.1	7	1323.7
1	511.7	1	936.4	15	1335.0
1	517.6	4	945.6	1	1356.2
2	530.3	0	954.4	5 Ca?	1362.6
2	533.3	0	960.6	4 Si, Ca?	1393.9
7	538.4	0	966.6	4 Si, Ca?	1402.9
2	543.5	12	977.1	1	1426.9
2	549.6	2 O, N?	991.1	1	1432.2
3	560.5	10	1010.2	2	1463.7
3	564.7	1	1022.8	1	1482.1
6	574.5	12	1036.7	4	1548.8
3	585.7	8 Si?	1066.0	3	1550.9
5	595.1	3 O, N?	1085.3	5	1561.3
1 O?	600.2	3	1092.6	1	1577.6
1 O?	609.5	3 Si, Ca?	1109.6	1 B?	1624.3
3	636.3	2	1111.3	5	1657.6
5	641.8	3	1137.4	2	1752.3
6	651.5	4	1141.5	1	1827.3
0	661.5	15	1175.6	0	1910.2
8	687.3	3	1194.1	7	1931.1
0	711.0	5 Ca?	1206.6		
0	743.6	2	1230.2		

TABLE III

NICKEL SPECTRUM*

Intensity	λ	Intensity	λ	Intensity	λ
0	731.0	1	1417.1	0	1662.7
0 C?	786.2	1	1420.9	1	1673.2
0	861.0	1	1429.0	1	1688.9
0 C?	944.7	0	1430.9	2	1693.4
1	1072.7	1	1435.2	2	1708.4
1	1079.0	1	1439.6	2	1710.9
1 C?	1084.0	1	1445.4	2	1716.2
0	1091.6	0	1449.5	1	1720.2
0	1100.6	1	1452.8	1	1724.0
0	1107.2	0	1455.6	0	1734.2
0	1118.0	1	1462.6	1	1739.4
0	1224.4	1	1468.9	1	1742.7
1	1234.2	1	1477.6	2	1748.2
1	1245.0	1	1483.5	2	1753.7
1	1253.0	0	1490.6	1	1765.5
1	1265.9	1	1494.0	2	1770.3
1	1277.0	2	1499.7	1 Al?	1777.0
1	1306.7	1	1513.8	0	1789.1
1	1314.6	0	1517.5	1	1792.1
1	1318.4	1	1521.6	0	1795.7
0	1346.6	2	1527.4	1	1812.3
0	1351.2	1	1535.6	0	1820.2
1	1357.3	0	1539.1	1	1824.0
0	1364.3	1	1544.3	1	1831.0
1	1372.2	1 C?	1561.5	0	1848.5
0	1382.4	1 Al?	1606.3	0	1850.7
1	1386.6	0 Al?	1613.0	1 Al?	1855.2
2	1398.5	0	1621.2	0	1859.7
2	1411.3	1	1653.8		

*The spectrum of nickel between 700 and 200 angstroms, to which point it has recently been carried, will be reported upon later.

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January 1921

INTENSITY DIFFERENCES IN FURNACE AND ARC AMONG THE COMPONENT SERIES IN BAND SPECTRA[1]

By ARTHUR S. KING

ABSTRACT

Intensity differences between band spectra emitted by electric furnace and by arc.—Large-scale photographs of the "*cyanogen*" *band at* λ *3883*, made in the third order of a 30-foot spectrograph, showed the A_1 series of lines is enhanced over the A_2 series so as to become the dominant series (Plate II). Also some new faint doublet appeared. The two series, then, seem not to belong to the same temperature class, and may be expected to be differently affected by pressure, etc. The "*cyanogen*" *band at* λ*4216* also showed similar changes. In the *Swan band* λ *5165* the triplet series is enhanced in the furnace spectrum with reference to the adjacent doublet series.

In spectrograms of moderate dispersion in which the spectrum of the electric furnace was photographed with comparison arc spectra, it was noted that the "cyanogen" band λ 3883, which frequently appeared, showed an apparent difference in structure, the component lines seeming to be more numerous in the furnace when the general intensity was about the same for both sources. Closer examination showed this to be due to an intensification in the furnace of band lines which are present but relatively faint in the arc.

Since the phenomenon indicated a variability among band lines similar to that generally observed for line spectra given by arc and furnace, the nature of the difference was investigated with higher dispersion, the third order of the 30-foot plane grating spectrograph being used. As this band is emitted more strongly at atmospheric pressure than in the vacuum furnace, and as it was desirable furthermore to avoid differences of pressure, a new furnace built to stand long exposures at high temperatures was employed. In this, the graphite tube is supported in large bronze holders, cast hollow for water-cooling, with graphite bushings around the ends of the tube. The heated portion of the tube is protected merely by a cast-iron water jacket which retards the wasting away of the

[1] *Contributions from the Mount Wilson Observatory*, No. 194.

tube by preventing active circulation of air. Large-scale photographs were thus secured for tube temperatures of approximately 2700°, 2500°, and 2350° C., a spectrum of the carbon arc being taken in each case adjacent to that of the furnace.

The portion of the band between the first and second heads, being free from the overlapping which occurs beyond the second head, was most suitable for comparison. It was clear that the different appearance in furnace and arc is due to an enhancement in the furnace of the series of lines designated by Uhler and Patterson[1] as "A_1." This is weaker in the arc than the "A_2" series, composed of doublets, up to a point not far from the head of λ 3883, some lines of the A_1 series being very faint in a normally exposed arc spectrum. In the furnace, A_1 is the dominant series. At 2350°, the A_1 lines are nearly twice as strong as those of the A_2 series. At 2500°, reversals begin for both series, but a much larger proportion of the A_1 lines is reversed. At 2700°, almost all members of both series are reversed, the reversals of A_1 lines being decidedly wider.

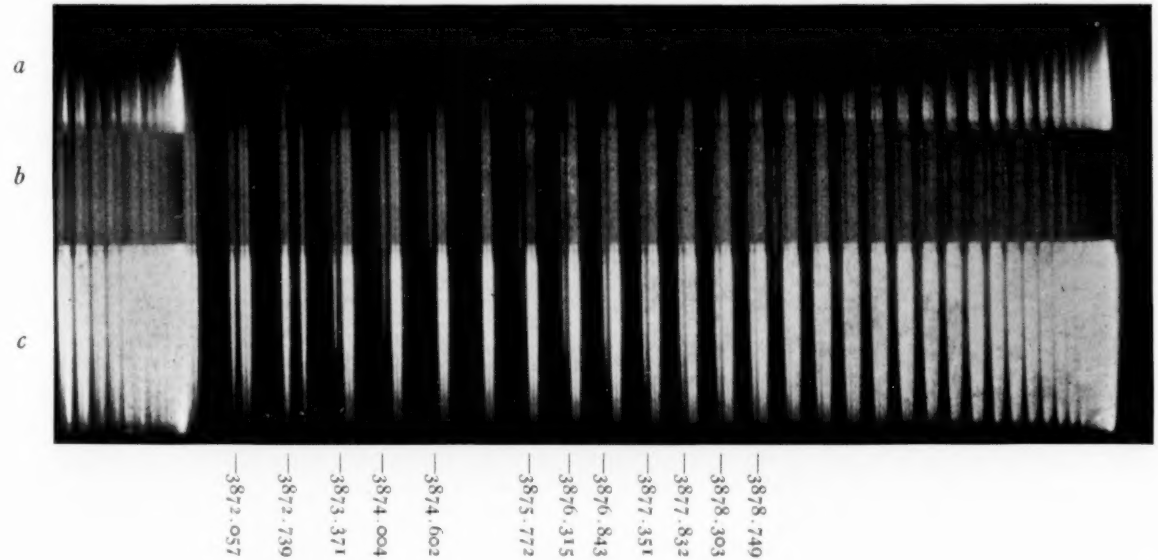
Plate II shows the section of the band most favorable for examination, with the furnace spectrum at 2500° between two arc spectra of different exposures.

In the following table a comparison is given of the band lines of arc and furnace for a portion of this region. The wave-lengths are those of Uhler and Patterson, and the series symbols and intensities for the arc lines are also taken from their paper. *F* and *f* indicate degrees of faintness, while *w*, *m*, and *i* signify weak, medium, and strong, respectively. The same gradation is adopted for the furnace spectrum and degrees of reversal are indicated by *r* and *R*. The intensity relations for the remaining lines up to the head at λ 3883 are similar to those of the last three lines in the table.

In addition to strengthening the A_1 series (and perhaps others beyond the second head), a series of faint doublets, not quite strong enough to measure, appears in the furnace band between $\lambda\lambda$ 3871 and 3875. These do not show in the arc band even when this is very strong. The furnace thus appears to be especially effective in bringing out the full structure of a band.

[1] *Astrophysical Journal*, **42**, 434, 1915.

PLATE II



Section of λ 3883 band in furnace (*b*) and arc (*a*, *c*), showing high intensity of A_1 series of single lines (marked) in furnace as compared with A series of doublets.

An examination of the "cyanogen" band at λ 4216 and that at λ 5165 belonging to the Swan spectrum, the latter being photographed in furnace and arc under high dispersion, showed in each case a strengthening of certain series by the furnace. The triplet

TABLE I

INTENSITIES OF BAND LINES IN ARC AND FURNACE

λ	Series	Arc (U and P)	Furnace
3872.057	A_1	*m*	*i r*
.180	A_2	*i*	*m*
.252	A_2	*i*	*m*
.739	A_1	*i*	*i r**
.965	A_2	*m*	*m*
3873.371	A_1	*w*	*i r*
.501	A_2	*i*	*m*
.567	A_2	*i*	*m*
3874.004	A_1	*f*	*i*
.123	A_2	*i*	*m*
.190	A_2	*i*	*m*
.602	A_1	*F*	*i*
.727	A_2	*i*	*m*
.791	A_2	*i*	*m*
3875.310	A_2	*i*	*m*
.375	A_2	*i*	*m*
.772	A_1	*F*	*i*
.873	A_2	*i*	*i*
.939	A_2	*i*	*i*
3876.315	A_1	*f*	*i*
.415	A_2	*i*	*i*
.481	A_2	*i*	*i*
.843	A_1	*w*	*i r*
.938	A_2	*i*	*i*
3877.005	A_2	*i*	*i*
.351	A_1	*w*	*i r*
.446	A_2	*i*	*i*
.506	A_2	*i*	*i*
.832	A_1	*m*	*i R*
.925	A_2	*i*	*i r*
.989	A_2	*i*	*i r*
3878.303	A_1	*m*	*i R*
.389	A_2	*i*	*i r*
.448	A_2	*i*	*i r*
.749	A_1	*i*	*i R*
.828	A_2	*i*	*i r*
.891	A_2	*i*	*i r*

* Double violet component reversed in furnace.

series proceeding from the head at λ 5165 is enhanced in the furnace to about the intensity of the strongest line of the adjacent doublet series, thus doing away with the contrast which the arc shows on account of the predominance of the doublet series.

The question as to whether temperature produces the difference between furnace and arc cannot well be tested at present, on account of the great increase in vapor density, with resulting reversals, when the graphite tube is heated to high temperature. A considerable difference in temperature, such as between 2300° and 2700°, involves the uncertainty of comparing sharp and reversed lines. The difference between furnace and arc indicates, however, that the contrasted series belong in different temperature classes. If so, there should be a difference in their response to displacing agencies such as pressure or those electrical actions which affect wave-length, since, for the line-spectra of metals, lines relatively strong in the furnace are less subject to displacements.

A further feature resulting from the fact that the lines composing a band do not behave as a unit is that this dissimilarity must be taken into account in atomic models designed to explain the radiation of band spectra. A considerable degree of independence evidently exists between the centers emitting the component series of a band which itself is a member of a family of bands.

Mount Wilson Observatory
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ELEMENTS OF THE ECLIPSING SYSTEM SX CASSIOPEIAE

By MARY FOWLER[1]

ABSTRACT

Eclipsing system SX Cassiopeiae.—From the normals obtained from the later (1915) observations of Luizet, the *elements of the system* have been computed (Table II). The *light-curve* at the minima is given and also a *picture of the system.* The stars are both giants with radii about 13 and 10, and brightness about 100 and 24, respectively, in terms of the sun. The primary eclipse is annular, the secondary total.

For this star ($\alpha = 0^h 5^m.5$, $\delta = +54°20'$ for 1900.0) Shapley[2] published elements based on observations by Luizet,[3] and Luizet later[4] published further observations, upon which the present elements are based. These observations are not so numerous as

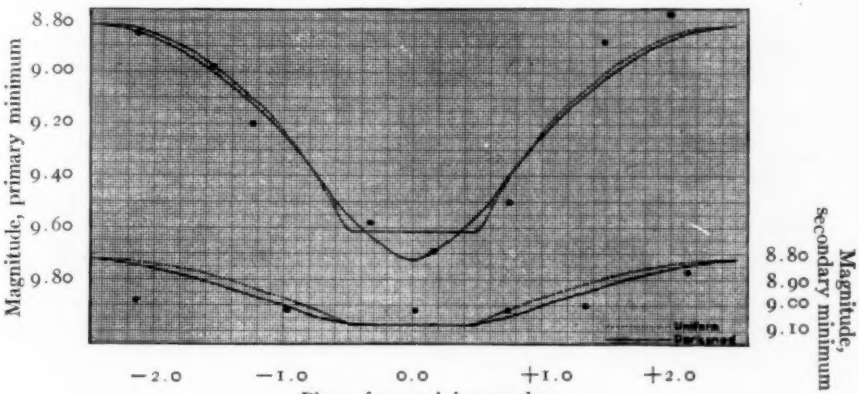

FIG. 1.—Light-curve of SX Cassiopeiae at the eclipses

those for RT Lacertae, nor do they give as smooth a curve, particularly around secondary minimum. They are reduced to the magnitude scale in the same way as those for RT Lacertae, but in this case Luizet's normals are taken singly, not in pairs.

[1] This paper was chiefly prepared by Miss Fowler before the war, and completed by me at Professor Russell's request.—Bancroft Walker Sitterly.

[2] *Contributions from the Princeton University Observatory*, No. 3.

[3] *Bulletin Astronomique*, **26**, 278, 1909. [4] *Ibid.*, **32**, 66, 1915.

Both minima are fairly deep—the combined loss of light is about 80 per cent; and the shape of the curve in its uneclipsed portion indicates a high degree of ellipticity in the figures of the spheroidal stars. After "rectifying" for this, as usual, "uniform" and "darkened" solutions were made. The first gave an orbital inclination over 87°, so, in the second, central transit was assumed in order to make the theoretical curve steep enough at the eclipses, and even this did not give a very close fit. The "darkened" assumption is just a trifle the better fit all over. Both solutions make the larger star the

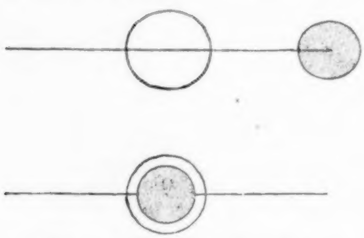

FIG. 2.—SX Cassiopeiae at elongation and at primary minimum, according to the "darkened" solution.

TABLE I

TABLE OF OBSERVATIONS, SX CASSIOPEIAE

No.	Phase	Observed Magnitude	O.–C. Uniform	O.–C. Darkened	No.	Phase	Observed Magnitude	O.–C. Uniform	O.–C. Darkened
	Days					Days			
1	0.158	9.69	$+0\overset{\mathrm{M}}{.}06$	$-0\overset{\mathrm{M}}{.}01$	20	18.303	9.02	$-0\overset{\mathrm{M}}{.}05$	$-0\overset{\mathrm{M}}{.}05$
2	0.746	9.50	+0.10	+0.10	21	19.025	9.02	0.00	−0.02
3	1.482	8.88	−0.12	−0.14	22	19.626	9.00	+0.08	+0.06
4	1.984	8.77	−0.09	−0.11	23	20.413	8.87	+0.04	+0.02
5	2.462	8.76	−0.06		24	21.360	8.84	+0.04	
6	3.186	8.79	−0.01		25	22.191	8.78	−0.01	
7	3.958	8.76	−0.03		26	22.905	8.75	−0.02	
8	4.962	8.74	−0.03		27	24.093	8.73	−0.01	
9	6.199	8.74	0.00		28	25.449	8.72	0.00	
10	7.639	8.73	+0.02		29	26.630	8.73	+0.03	
11	8.612	8.74	+0.03		30	27.820	8.71	0.00	
12	9.418	8.69	−0.01		31	29.117	8.75	+0.04	
13	10.246	8.71	0.00		32	30.647	8.76	+0.02	
14	11.597	8.72	−0.01		33	31.956	8.81	+0.04	
15	12.602	8.68	−0.06		34	33.350	8.82	+0.01	
16	13.849	8.74	−0.03		35	34.430	8.85	+0.02	0.00
17	15.082	8.82	+0.01		36	35.018	8.98	0.00	−0.03
18	16.156	8.98	+0.16	+0.14	37	35.326	9.20	+0.09	+0.08
19	17.320	9.03	+0.050	+0.02	38	36.232	9.58	−0.04	−0.04

Probable error of one normal, on "uniform" hypothesis, $\pm 0\overset{\mathrm{M}}{.}0357$; on "darkened" hypothesis, $\pm 0\overset{\mathrm{M}}{.}0344$.

brighter, so that primary eclipse is annular and secondary total, a condition opposite to that of Shapley's solution.

Adams and Joy[1] give the spectrum of the bright component of the system as "very much like that of a Cygni." Only one spectrum was visible, confirming the present orbit's indication that the stars are very unequal in brightness. Computation by Shapley's methods[2] of the hypothetical dimensions and distance shows that these stars are emphatically "giants," as their low density would suggest.

TABLE II

TABLE OF ELEMENTS, SX CASSIOPEIAE

EPOCH AND PERIOD=J.D. 2417983.45 G.M.T.±0.17+(36.5668±0.0041) E

Element	Symbol	Value: Uniform	Value: Darkened
Ratio of radii of stars	k	0.800	0.735
Type of eclipse:			
Primary		Annular	Annular
Secondary		Total	Total
Semi-major axis:			
Brighter star	a_b	0.232	0.260
Fainter star	a_f	0.186	0.191
Semi-minor axis:			
Brighter star	b_b	0.204	0.241
Fainter star	b_f	0.163	0.177
Eccentricity of meridian section of stars	$\epsilon=\sqrt{z \cdot \operatorname{cosec}^2 i}$	0.484	0.382
Inclination of orbit	i	87°40′	90°0′
Least apparent distance of centers	$\cos i$	0.041	0.000
Light of brighter star	L_b	0.810	0.809
Light of fainter star	L_f	0.190	0.191
Ratio of surface brightness of stars	J_b/J_f	2.73	2.29
Density of stars in terms of sun:			
Brighter star	$\bar{\rho}_b$	0.0004	0.0003
Fainter star	$\bar{\rho}_f$	0.0008	0.0007
Light of brighter star in terms of sun	$\bar{L}_b$	100	
Greatest radius of stars in terms of sun:			
Brighter star	$\bar{a}_b$	13.5	15.2
Fainter star	$\bar{a}_f$	10.9	11.2
Absolute magnitude of brighter star	$\bar{M}_b$	−3.7	
Parallax	π	0″00029	
Distance in light-years		11000	
Spectral type		A2	

Table I gives the normals and residuals, and Table II the elements. The light-curve at the minima is shown in Figure 1, while Figure 2 pictures the system.

PRINCETON UNIVERSITY OBSERVATORY
August 1920

[1] *Publications of the Astronomical Society of the Pacific*, **31**, 308, 1919.

[2] *Contributions from the Princeton University Observatory*, No. 3, pp. 9, 117.

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